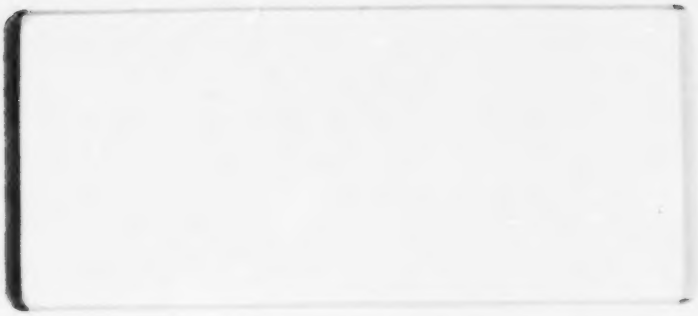

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TP # 6922E

ICE MANAGEMENT IN THUNDER BAY HARBOUR

PERFORMANCE OF A PERMANENT AIR BUBBLER SYSTEM

WINTER 1984/85

TRANSPORTATION DEVELOPMENT CENTRE

JULY 1985

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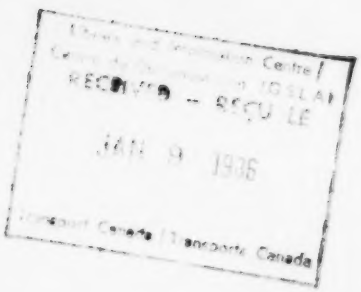

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17. Abstract

The results of tests conducted during February and March 1985 to evaluate the performance of a new permanent air bubbler system installed at a slip in a harbour at Thunder Bay, Ontario, are reported. Instrumentation was installed to monitor ambient thermal condition of air, ice cover and water in the test area. Temperature records were taken for four weeks prior to activating the bubbler system and one week during bubbler operation. Analysis was designed to establish the source of melting effect, the rate of ice melt, the effectiveness and the considerations of the ice melt process. The results indicated that the permanent air bubbler system worked satisfactorily and melted ice at a rate of approximately 100 m^2 per day, approximately half the rate of the air cannon bubbler system.

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17. Résumé

Ce rapport décrit les essais effectués dans le port de Thunder Bay en février et mars 1985 pour évaluer l'efficacité d'un système de déglaçage mettant en oeuvre des diffuseurs d'air installés en permanence au fond d'un des bassins de chargement. La température de l'air, de l'eau et de la glace a été contrôlée durant les quatre semaines qui ont précédé les essais ainsi que durant la première semaine de mise en marche des diffuseurs. L'analyse des résultats visait à déterminer la vitesse de déglaçage, les facteurs en oeuvre, les mécanismes de la fonte et l'efficacité de la technique utilisée. Le système essayé s'est avéré satisfaisant, avec une vitesse de déglaçage d'environ 100 $2m$ /jour, soit environ la moitié de celle des mélangeurs à canon pneumatique.

18. Mots-clés	19. Diffusion
Diffuseur d'air, maîtrise des glaces, contrôle de la température, port, bassin de chargement, potentiel thermique	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires

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SUMMARY

This report presents the results of tests of an air bubbler system conducted in the Port of Thunder Bay in March 1985. This project is part of an on-going ice control research program sponsored by the Transportation Development Centre of Transport Canada.

The tests evaluated an air bubbler permanently installed at Saskatchewan Wheat Pool 7A slip to determine:

- effectiveness in moving deep warm water to surface
- ice melting rate
- source of melting effect
- cost per unit of ice melted

Ambient thermal condition of the air, ice cover and water in the test area was monitored from February 8, 1985, to March 12, 1985. The bubbler system was operated from March 12 to March 22 and data was collected for the initial 90 hours of operation.

The results indicated that the air bubbler system worked satisfactorily at a cost comparable to or lower than that of previously tested bubbler systems. The bubbler was able to transport warmer, deep water to the surface effectively, and to initiate water movement from surrounding regions of the slip, importing warmer water to the affected ice surface and drawing upon the thermal reserve of the water in the slip and the soil beneath the slip.

The air bubbler exhibited several minor problems of maintenance and operations; solutions to overcome these are given. Recommendations for additional study and future work are made.

SOMMAIRE

Ce rapport rend compte de la mise à l'épreuve d'un système de déglaçage installé en permanence dans le port de Thunder Bay. Les essais, qui ont eu lieu en mars 1985, s'inscrivent dans un programme de recherche sur la maîtrise des glaces mené pour le compte du Centre de développement des transports de Transports Canada.

Le système de déglaçage qu'il s'agissait d'évaluer est installé dans le bassin de chargement 7A de la Saskatchewan Wheat Pool et met en oeuvre une batterie de diffuseurs d'air. Les essais avaient pour but de déterminer:

- la capacité des diffuseurs à faire monter à la surface l'eau relativement chaude du fond du bassin;
- la vitesse de déglaçage;
- la cause agissante de la fonte des glaces;
- le coût par unité de volume de glace fondue.

La température de l'air, de l'eau et de la glace a été contrôlée du 8 février au 12 mars, puis durant les 90 premières heures de mise en marche des diffuseurs. Ceux-ci ont été maintenus en marche du 12 au 22 mars.

Les résultats obtenus ont été jugés satisfaisants. Les diffuseurs réussissent non seulement à faire remonter l'eau du fond du bassin à la surface, mais aussi à provoquer un apport d'eau de l'extérieur du bassin, amenant dans chaque cas une eau relativement chaude en contact avec la couche de glace de la zone à dégager. Ils mettent en oeuvre le potentiel thermique de l'eau du bassin comme du sol sous-jacent. De plus, leur coût d'exploitation est équivalent ou inférieur à celui d'autres diffuseurs essayés préalablement.

Par contre, les diffuseurs ont posé plusieurs légers problèmes d'entretien et d'exploitation. Le présent rapport propose quelques solutions et présente des recommandations quant au sens dans lequel les travaux et recherches devraient être poursuivis.

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1.0 INTRODUCTION

1.1 Ice Management

Ice management has a long history of success and is quickly becoming the option of choice by engineers and managers around the northern hemisphere to guarantee the navigation season in waterways and harbours.

The major efforts by Transport Canada in recent years to investigate harbour ice management have resulted in considerable progress in ensuring timely navigation season openings, especially the program at the Port of Thunder Bay. These projects have included: the development of an air cushion icebreaking bow (ACIB), the installation of an air cannon bubbler developed by Atara Corporation (Murphy, 1982), installation of bubbler systems in two slips (Hill, 1980; Kamo and Nelson, 1982 & 1983), measurement of water temperatures in various slips (Abdelnour, 1983; Abdelnour et al, 1984), evaluation of an Archimedean Screw Tractor (AST) (Miller et al, 1983), review of various ice management alternatives (Gill and Cammaert, 1983) and ice management techniques evaluation (Abdelnour and Sayed, 1982).

1.2 Objectives

The overall objective of this study was to evaluate the performance of the new permanent air bubbler system installed at the harbour end of the Saskatchewan Wheat Pool 7A slip.

Specifically, four sub-objectives were identified, based on the following questions:

How effective is the system in moving deep water to the ice?

What rate of ice melting was initiated by the system?

What is the source of the melting effect?

What is the cost per unit of ice melted?

This report documents the study project that answered these questions, based on field work and analyses conducted during February - March, 1985 at the Port of Thunder Bay.

2.0 BACKGROUND: REQUIREMENTS FOR ICE MANAGEMENT

Increases in grain traffic through the Port of Thunder Bay over the last decade (up from 12 million tonnes in 1977 to nearly 20 million tonnes in 1984) have resulted in pressures to expand port capacities. One of the solutions proposed to solve this problem was to guarantee the opening of the terminal facility following the ice season at a fixed date.

This method has the advantage of reducing uncertainty in scheduling the facilities as well as improving the overall efficiency of the harbour.

A variety of ice management techniques have been proposed, tested and used to accomplish the task of securing a guaranteed spring opening date.

Of these, the use of bubbler systems to clear ice from slips and provide room for small icebreaker activities appears to be the most promising and cost-effective solution. This study extends the knowledge and experience with these systems in this application.

3.0 DESCRIPTION OF STUDY LOCATION

3.1 Site Description

The bubbler tests were conducted at Thunder Bay, Ontario, located on Lake Superior at latitude 48° N and longitude 89° W. Thunder Bay is at the western end of the Great Lakes waterway system and is 3200 km from the Atlantic Ocean.

Figure 3.1 illustrates the details of Thunder Bay Harbour and various slips where bubbling and other ice suppression tests have been undertaken by Transport Canada and Thunder Bay Harbour Commission, formerly Lakehead Harbour Commission. Air bubbler monitoring and operation for the present project took place at Saskatchewan Wheat Pool 7A.

Details of the test site are shown in Figures 3.2 through 3.4.

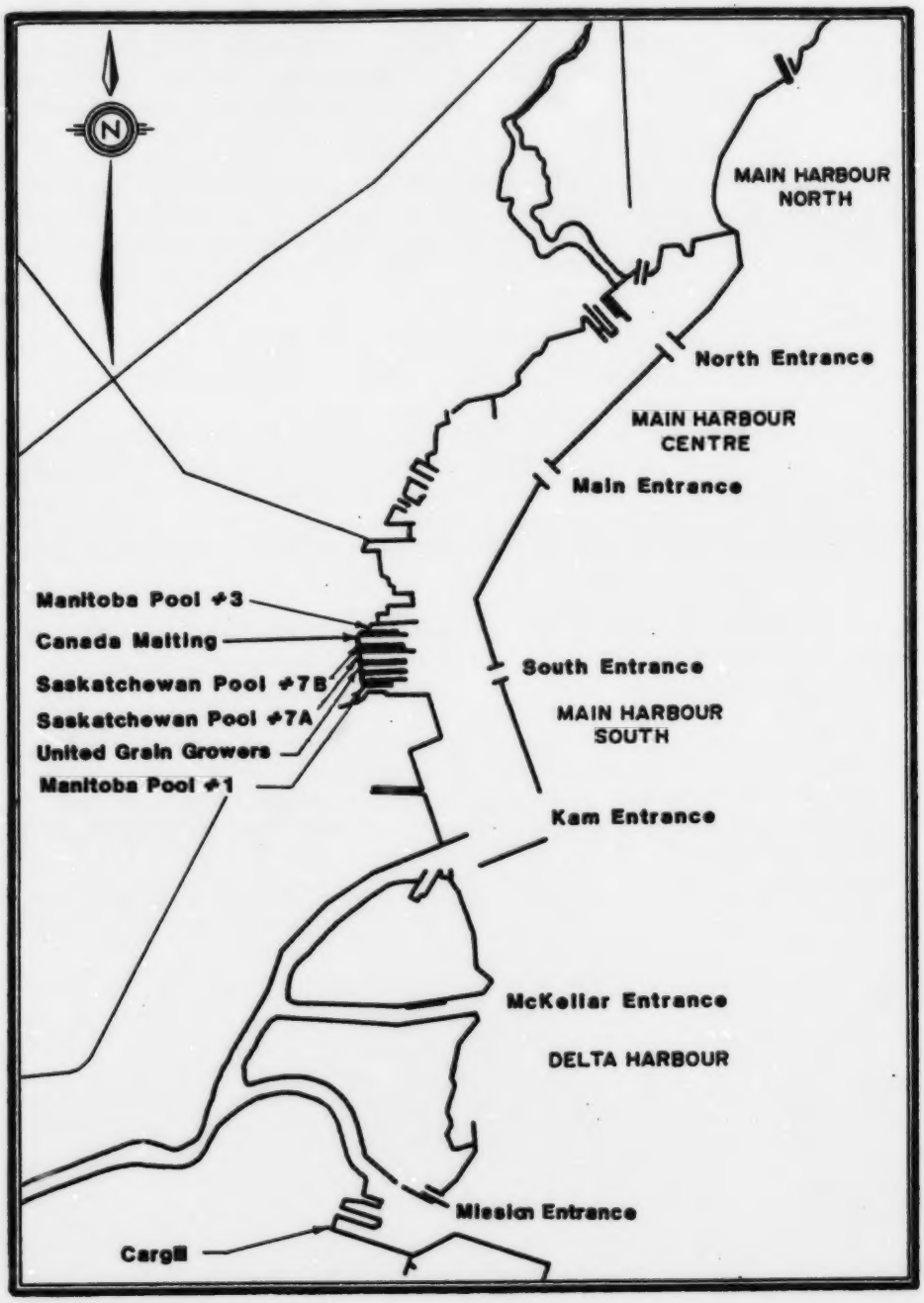
The air bubbler system used was installed by Saskatchewan Wheat Pool in 1984, as part of renovations to the 7A slip. It consists of fourteen (14) vertical pipes extending to within 0.5 m of the slip bottom. The pipes are spaced equally along 95 m of metal slip wall. Each pipe is curved outward at the bottom and ends with a 0.238 cm (3/32") nipple opening.

In order to operate the system, compressed air must be delivered to this region of the slip, with control and manifold equipment. The system is described in greater detail in Section 4.

Instrumentation for monitoring of the slip and air bubbler consisted of twenty-eight (28) thermistor sensors, controlled by computer equipment in a portable shack onshore, and a number of analog pressure gauges on the air bubbler system. The instrumentation is described more fully in both Sections 4 and 5.

FIGURE 3.1

THUNDER BAY HARBOUR



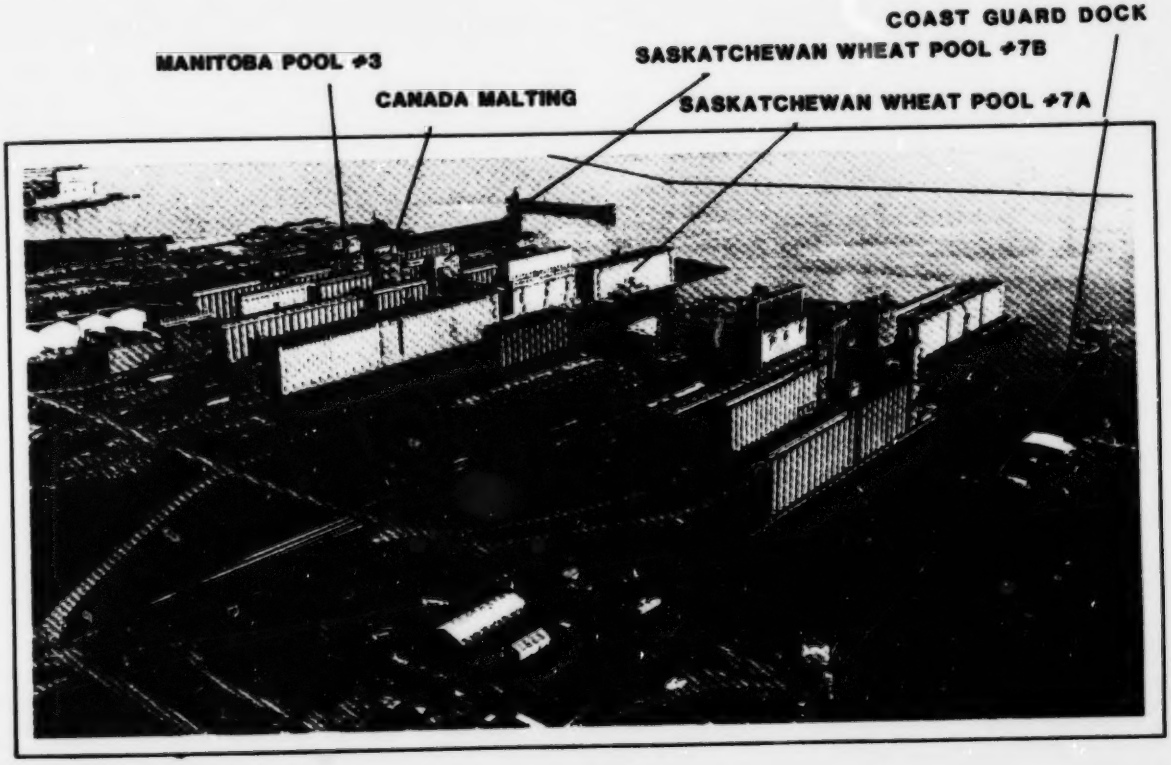


FIGURE 3.2

TEST SITE

FIGURE 3.3
VIEW OF TEST SITE

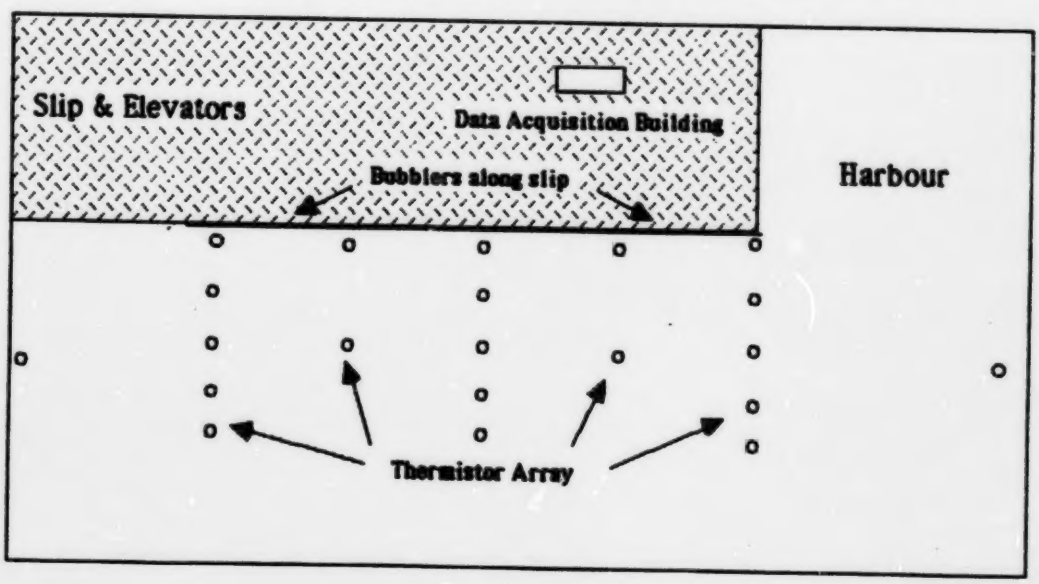


Figure 3.4
Plan View of Study Site

4.0 DESCRIPTION OF AIR BUBBLER SYSTEM

4.1 Overall System

The air bubbler system consists of three major components: the air source system, the delivery and distribution system and the bubbler units themselves.

The air source system made use of existing air compressor equipment at Saskatchewan Wheat Pool 7A. This consisted of two compressors, one of 200 cfm (5.7 m s-1) capacity, the other of 150 cfm (4.25 m^3 s-1) capacity. Primarily, the 200 cfm (5.7 m^3 s-1) unit was used. It was possible to obtain dried air (dew point -40°C), but this was less available during the day due to other uses, and was used at night only. A pressure storage tank was downstream from the compressors and cycled from 80 to 100 psi (550 to 690 kPa), approximately on a 60% duty cycle.

The delivery and distribution system began with a single 5 cm (2 inch) hose from the compressor pressure/storage tank to ground level on the slip walkway. This hose joined a length of pipe with a shut off valve, which then joined a series of 5 cm (2 inch) hoses which ran down the slip. These hoses were of mixed lengths, 15 and 30 m (50 and 100 feet) long, with metal hammer-type couplings. The total length of this hose run was 260 m (850 feet).

The 5 cm (2 inch) hose ran into a large manifold near the bubbler units. The manifold had 14 outlets for 2.5 cm (1 inch) connectors of quick connect type. From the manifold lengths of 2.5 cm (1 inch) hose ran out to each bubbler unit standpipe. The 2.5 cm (1 inch) hoses were of various lengths, ranging from 15 m (50 feet) to joined sections totalling 61 m (200 feet).

At the top of each bubbler unit the 2.5 cm (1 inch) hose joined a gate valve, secured to a dial-type pressure gauge. This assembly was directly attached to the bubbler unit top.

Each bubbler unit consisted of a length of 5 cm (2 inch) pipe, set vertically into the slip wall and extending to within 0.6 m of mudline. At this point a curving right angle fitting passed through the slip wall into the water. At the end, facing horizontal, was a nozzle with a hole 0.238cm (3/32 inch) in it.

Figure 4.1 illustrates the general layout of the system with all three major components shown. Figure 4.2 shows a more detailed schematic of the bubbler units.

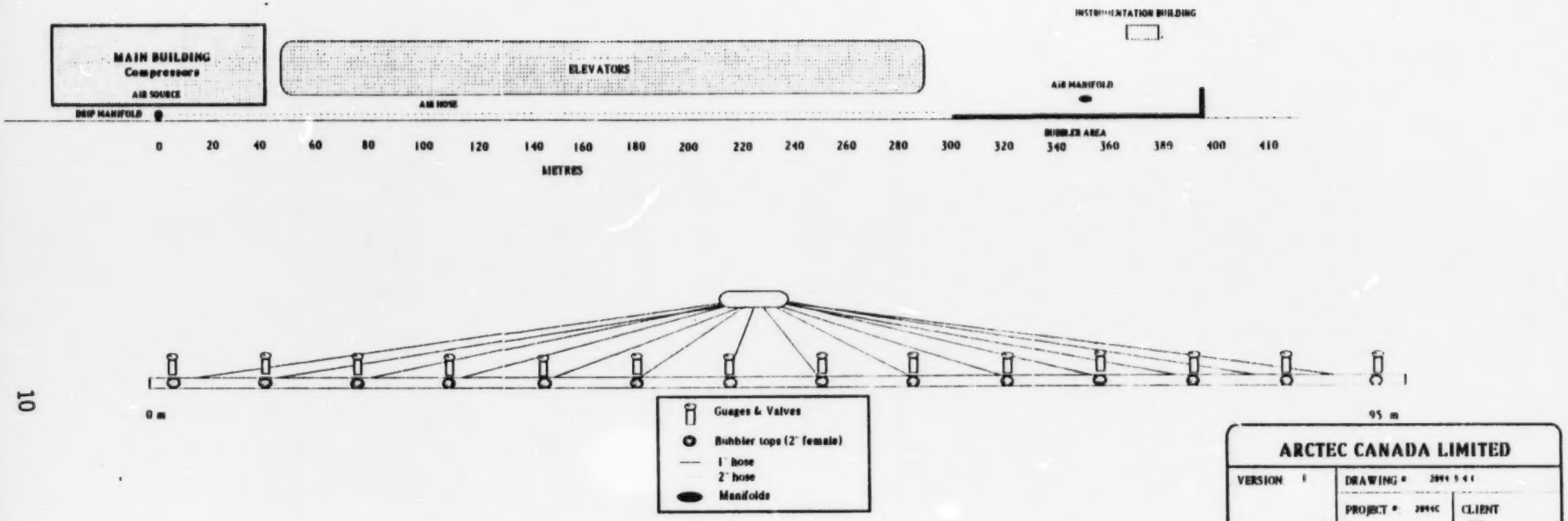


Figure 4.1
THUNDER BAY AIR BUBBLER SYSTEM AT SASKATCHEWAN POOL 7

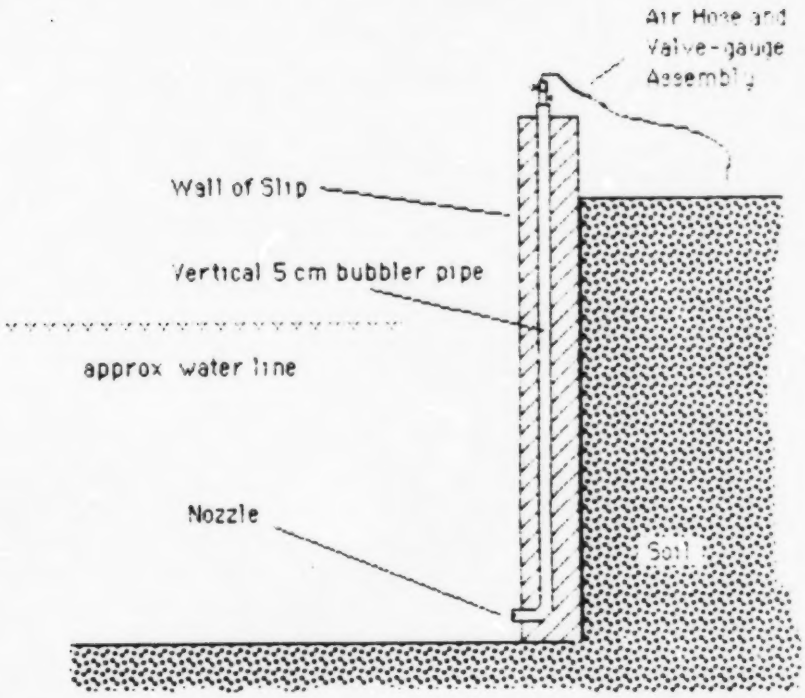


FIGURE 4.2
Example of Bubbler Unit Detail

5.0 DESCRIPTION OF INSTRUMENTATION FOR STUDY

5.1 Air Pressure Monitoring

As described in Section 4, air pressures at the top of each vertical bubbler pipe were monitored visually. This was done using standard compressed air gauges, ranging from 0 to 800 kPa. In order to ensure similar air flows in each bubbler, valves at the gauges were adjusted until all pressures, and therefore air flows, were the same for each unit.

These values were noted and are discussed further in Section 6.3.

5.2 Temperature Monitoring

5.2.1 Data Acquisition System Description

The temperature data acquisition system was comprised of three components: the sensors, the multiplexing scanner and controlling computer/data storage package.

The temperature sensors used were thermistors: Model YSI 44005. Twenty-eight (28) were deployed, with two spares and two for manual temperature sampling. Twenty-one (21) sensors were installed at a depth of 460 cm from the original ice surface. Seven others were installed at various depths for one location, ranging from 150 cm in the air to 800 cm below the surface. Figures 5.1 and 5.2 illustrate the deployment patterns.

The sensors were wired to an Hewlett-Packard HP3497A Multiplexing Scanner with built-in multimeter. This device was controlled by the computer and supplied the excitation current to the sensors and digitized the voltages from each sensor in turn. Communication to the computer was via HPIB.

The computer controlled the system via software which included user-variable parameters such as sample interval. It received the voltage readings and computed resistance values for each sensor, then calculated temperature values using the thermistor equation and the individual calibrations. Data from each reading were shown on the computer screen until updated, and all data were stored on floppy diskette with a time stamp from the on-board clock.

Figure 5.3 illustrates the data acquisition system.

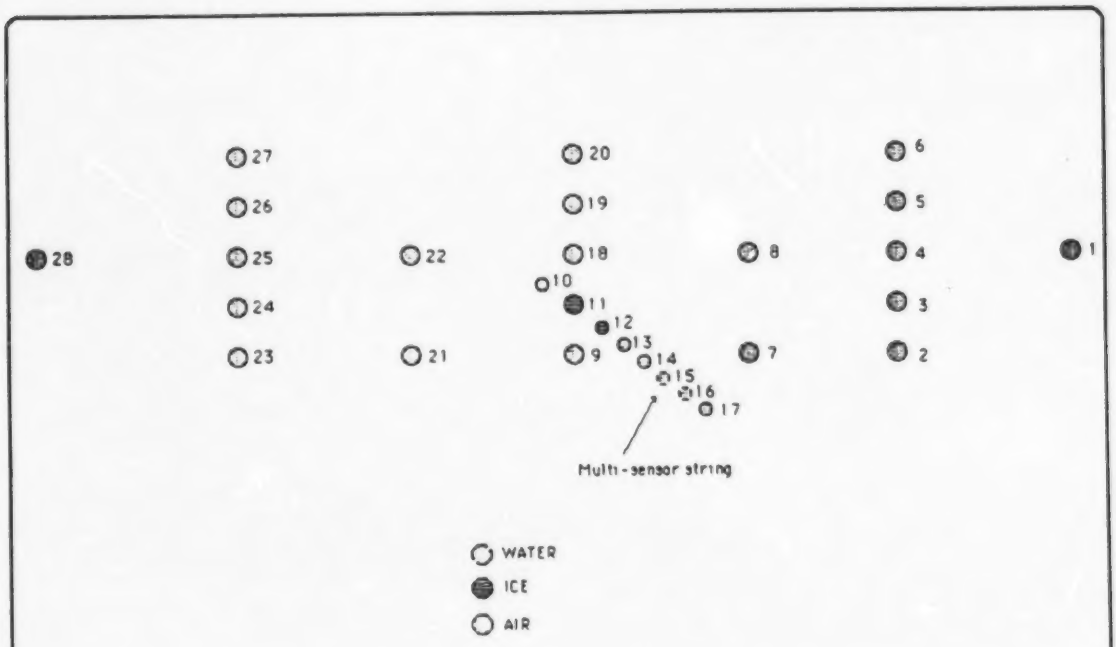


FIGURE 5.1
THUNDER BAY
THERMISTOR
ARRANGEMENT

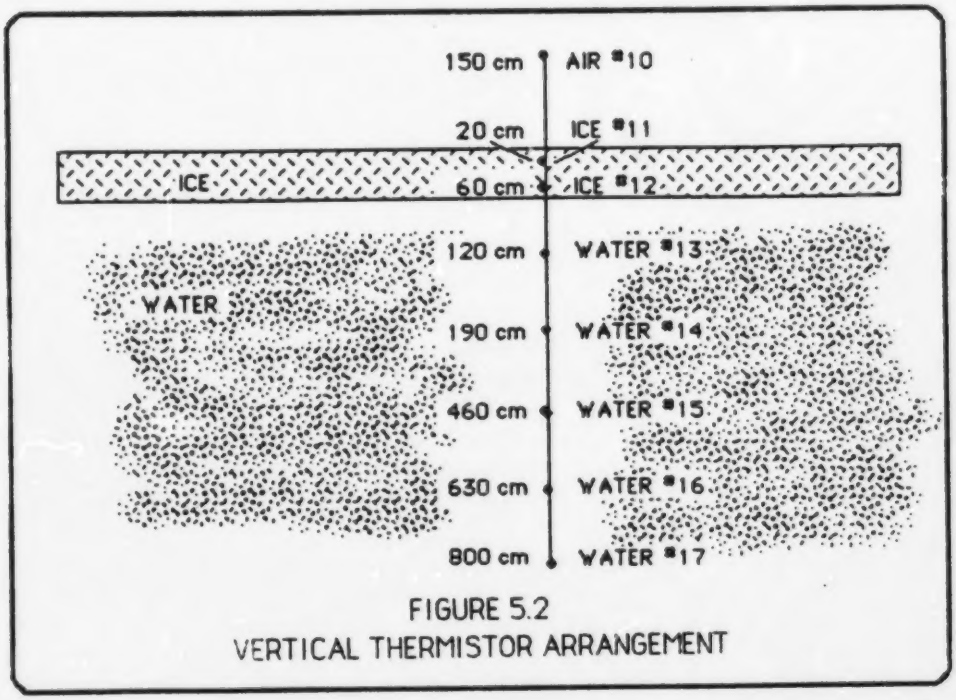


FIGURE 5.2
VERTICAL THERMISTOR ARRANGEMENT

5.2.2 Description of Data Acquisition Methods

The temperatures in the slip were monitored during two separate periods.

The first period was from February 8, 1985, through to March 12, 1985. During this time the sensors were scanned and data stored once every six hours. It was expected that this period of 745 hours would provide information about the ambient water and ice thermal situation in the area of the bubbler system. Any existing sources of heat, water stratification or vertical temperature variations would be indicated during this period.

The second period began March 12, 1985, and ran until March 16, 1985. It was during this ninety hour period that the bubbler system was initially operational (it was operated until March 22). The data were collected every hour during this time. This period was used for observation of the water and ice temperature variations under the action of the bubbler system.

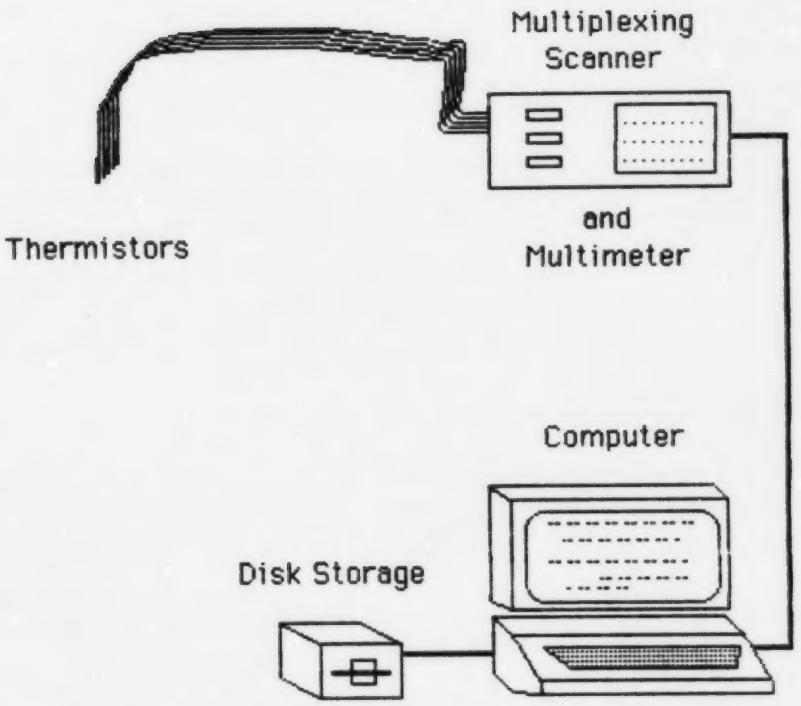


FIGURE 5.3
DATA ACQUISITION SYSTEM

6.0 RESULTS

The temperature data are compiled in complete form in Appendix A of this report.

6.1 Temperature Measurements, Ambient Conditions

6.1.1 Water Temperatures

The mean water temperature in early February at 4.6 m depth at the study site was 0.25°C. This rose throughout this portion of the study to a mean water temperature of 0.51°C in early March.

Compared to other years, the water in the slips was apparently cool, similar to the temperatures found in studies during 1983 and cooler than temperatures found in 1984 (Abdelnour et al, 1984).

An example of the spatial temperature patterns at this depth is illustrated in Figure 6.1. In this diagram of temperature isolines (contours) it is apparent that there is little variation in temperature over the area.

The vertical water temperature gradient at the site during this period is illustrated in Figure 6.2. Here, it is apparent that there is a vertical temperature gradient, from cooler water near the surface to warmer water at the bottom of the water column. Note that thermistor #14 shows temperatures below 0°C at several points: there are two likely explanations - one is that the water in the slip and harbour is contaminated and does not freeze at 0°C, but lower; the other is that there is a calibration offset or sensor problem.

6.1.2 Ice Temperatures

Ice temperatures were measured at one location only, at two depths: 20 cm and 60 cm below the ice surface.

The initial ice temperatures were -9.8°C and -0.21°C, respectively. The ice temperatures varied considerably, including a very cold period at the end of February, throughout the study period. These variations reflect the influence of surface air temperatures. By early March meltwater had entered the thermistor cable holes and temperatures rose to 0°C and above.

The temperature gradient through the ice sheet ascends with depth; warmer temperatures are typically observed at the deeper location.

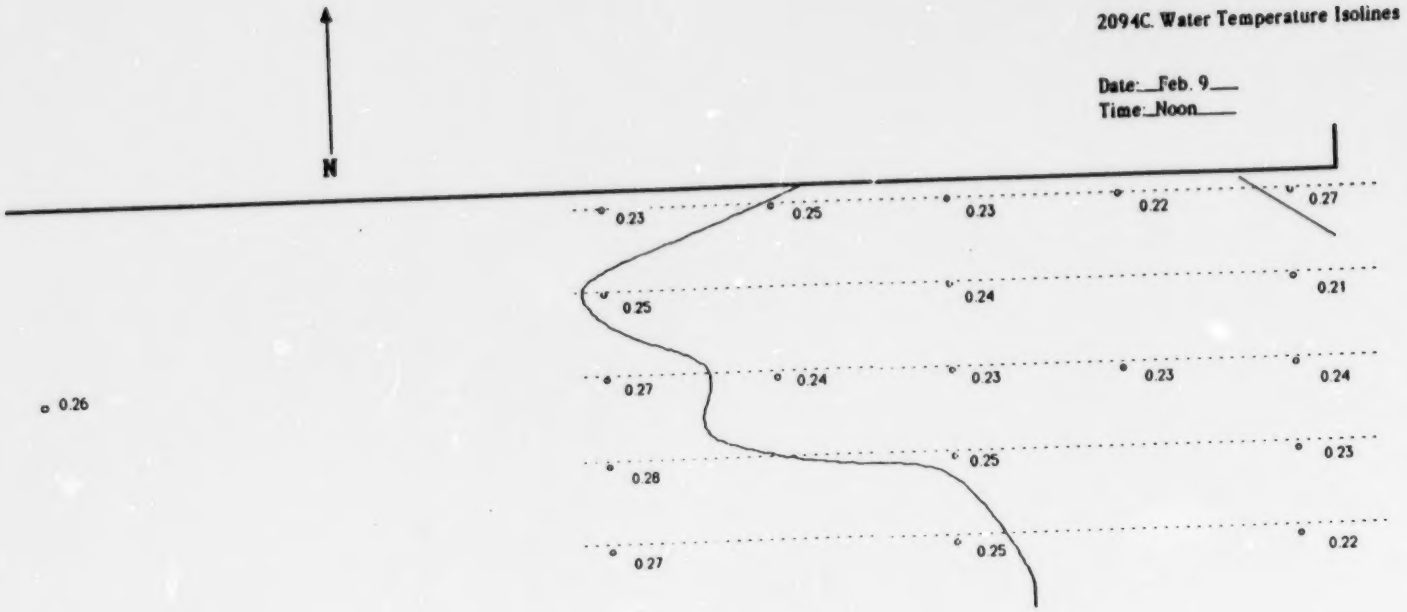


FIGURE 6.1
WATER TEMPERATURE ISOLINES

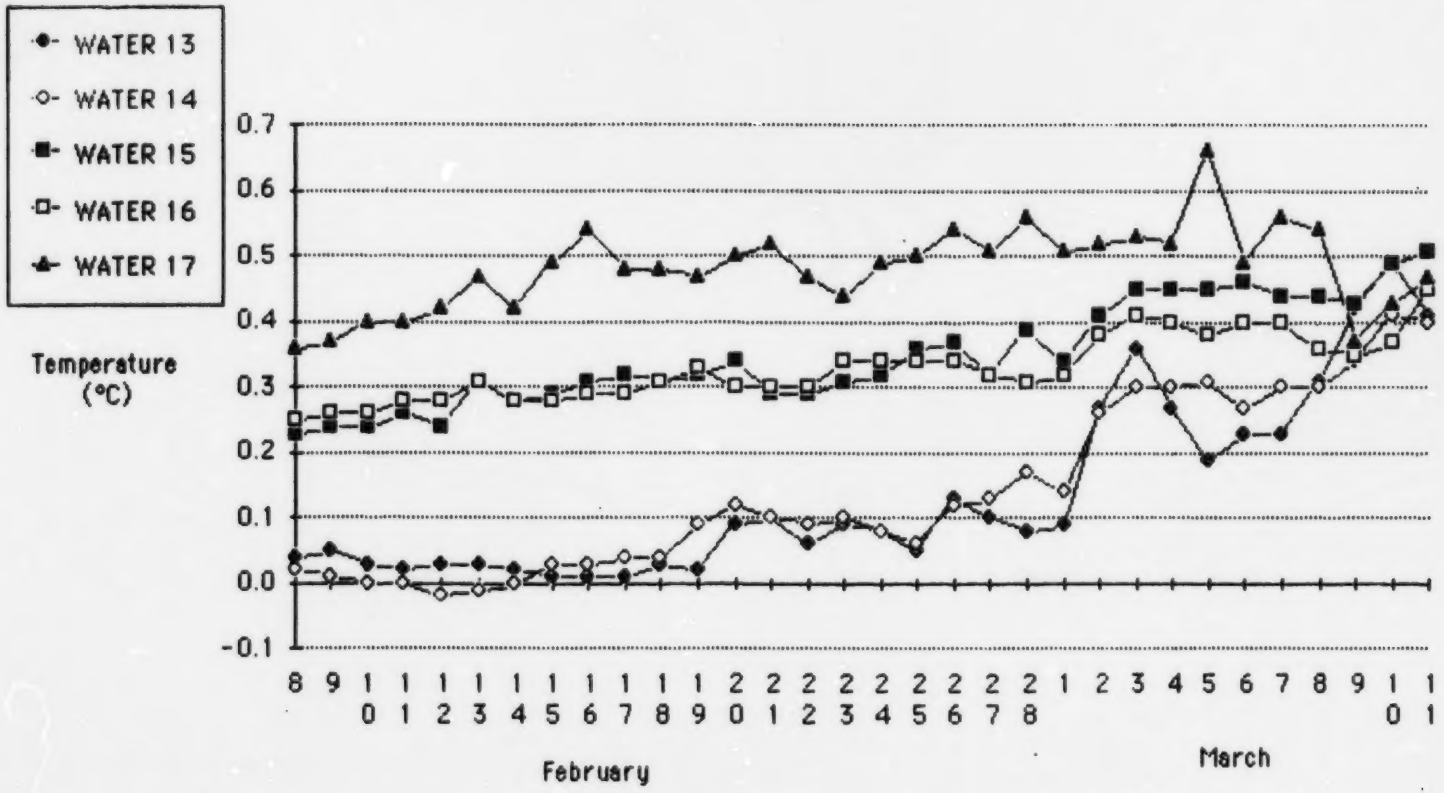


FIGURE 6.2
VERTICAL WATER TEMPERATURES

6.1.3 Air Temperatures

The air temperature was measured at one location, 1.5 m above the ice surface. The measured air temperatures reflect the diurnal variations at the site and indicate the general regional temperature shifts, reflecting the varying weather during the study period.

The maximum air temperature during this period was 7.8°C. The minimum temperature was -26.4°C and the mean temperature was -6.9°C.

6.2 Temperature Measurements During Bubbler Operation

6.2.1 Water Temperatures

Just prior to operation of the bubbler system, the data acquisition system was modified to sample the sensors once per hour.

During the ninety hours of monitoring, the mean temperature at 4.6 m depth rose from 0.57°C to 0.64°C. Individual thermistors provided maximum readings of 0.83°C and minimums of 0.45°C.

The spatial temperature changes at this depth are illustrated for the first 10 hours in Figure 6.3. These diagrams indicate that there is some initial warming along the bubbler line, continuing through the period shown. The movement of water causes cooler areas to show in the middle of the sampled area. By Figure 6.3e, much of the area appears to be well mixed and isothermal. The next figure, however, shows that the situation was not stable and cooler regions appear again.

The vertical water temperatures during this period are illustrated in Figure 6.4. This diagram shows that the water column initially warmed slightly over the first three hours, then generally cooled for a further twelve hours. Warming proceeded until the 25 hour mark. The deepest thermistor, #17, shows the most range and the most erratic observations.

The graph in Figure 6.5 shows daily vertical water temperatures for the entire study period, February 8 through March 16.

It is likely that the observations discussed here indicate the operational success of the bubbler system. When first turned on, it operated very well with the exception of two units. However, by the next morning, it was virtually non-operational as a result of ice blockages in the metal couplings of the large supply air hoses. Once these were cleared, it operated well. The timing of the second warming trend shown above corresponds well with the re-start of the bubbler system on March 13. For more discussion regarding the air bubbler operation, refer to Sections 6.3 and 10.0.

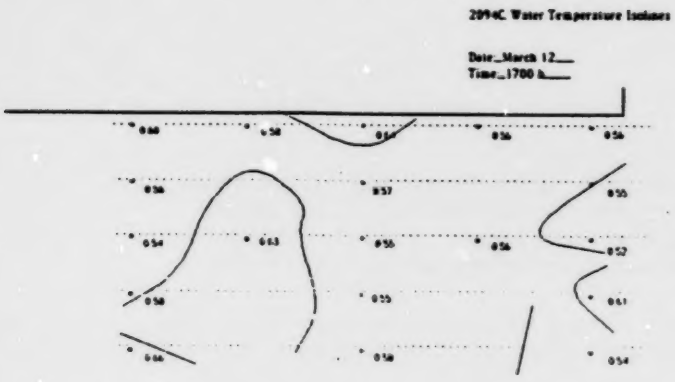


Figure 6.3a

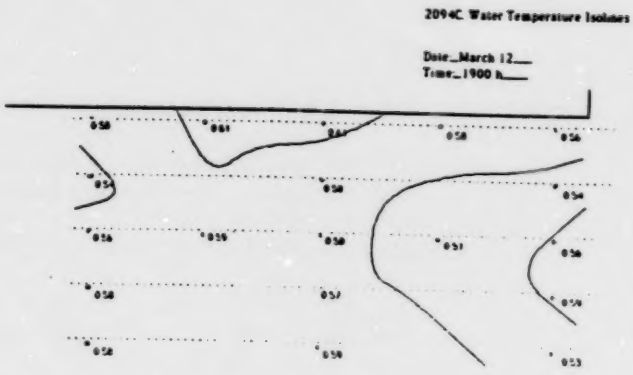


Figure 6.3b

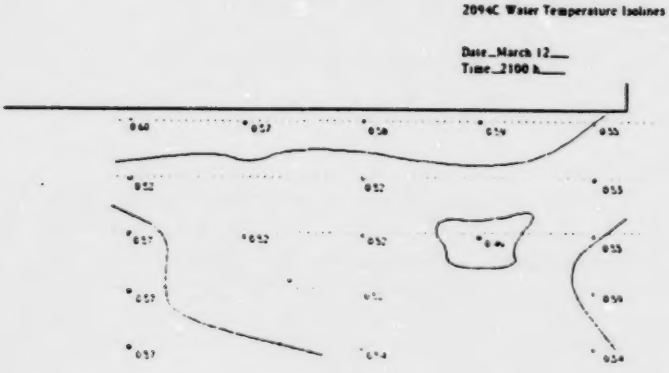


Figure 6.3c

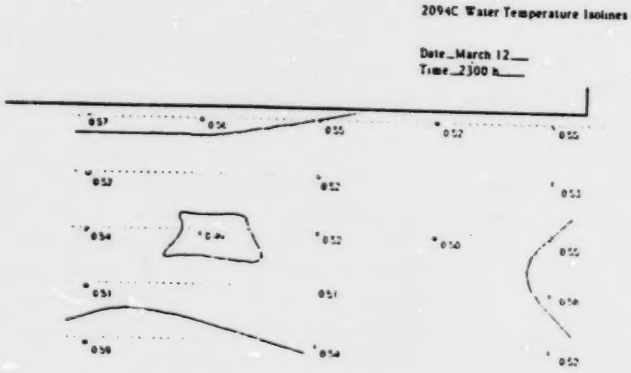


Figure 6.3d

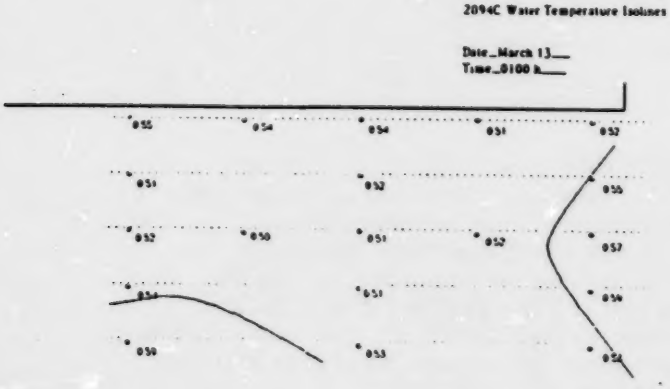


Figure 6.3e

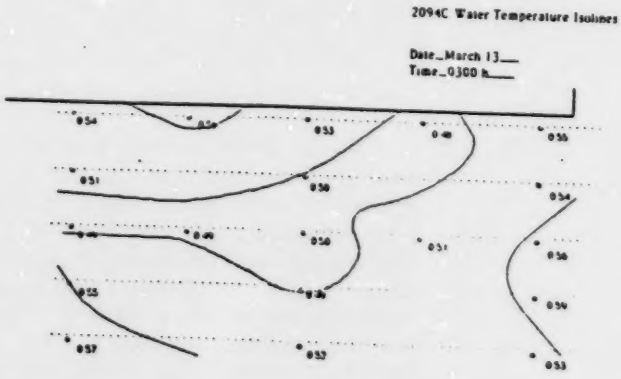


Figure 6.3f

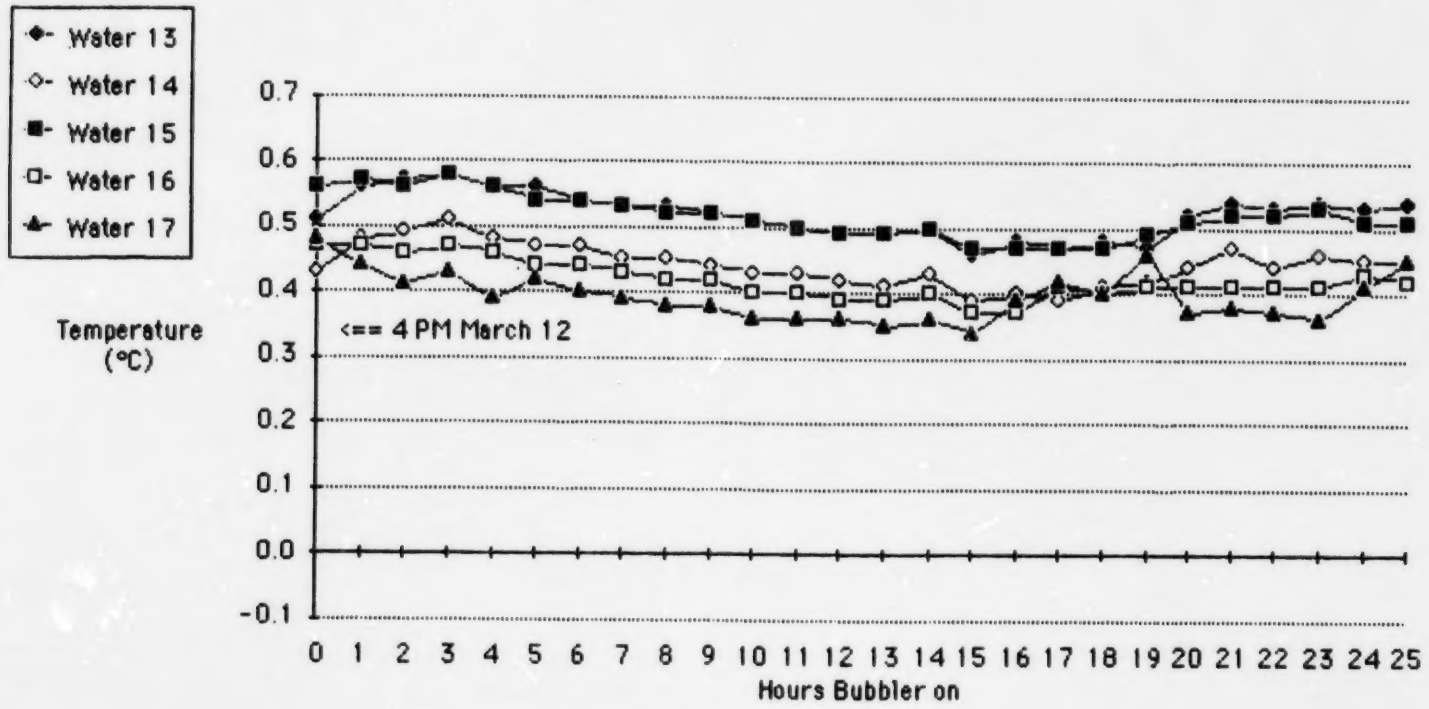


FIGURE 6.4
VERTICAL WATER TEMPERATURES

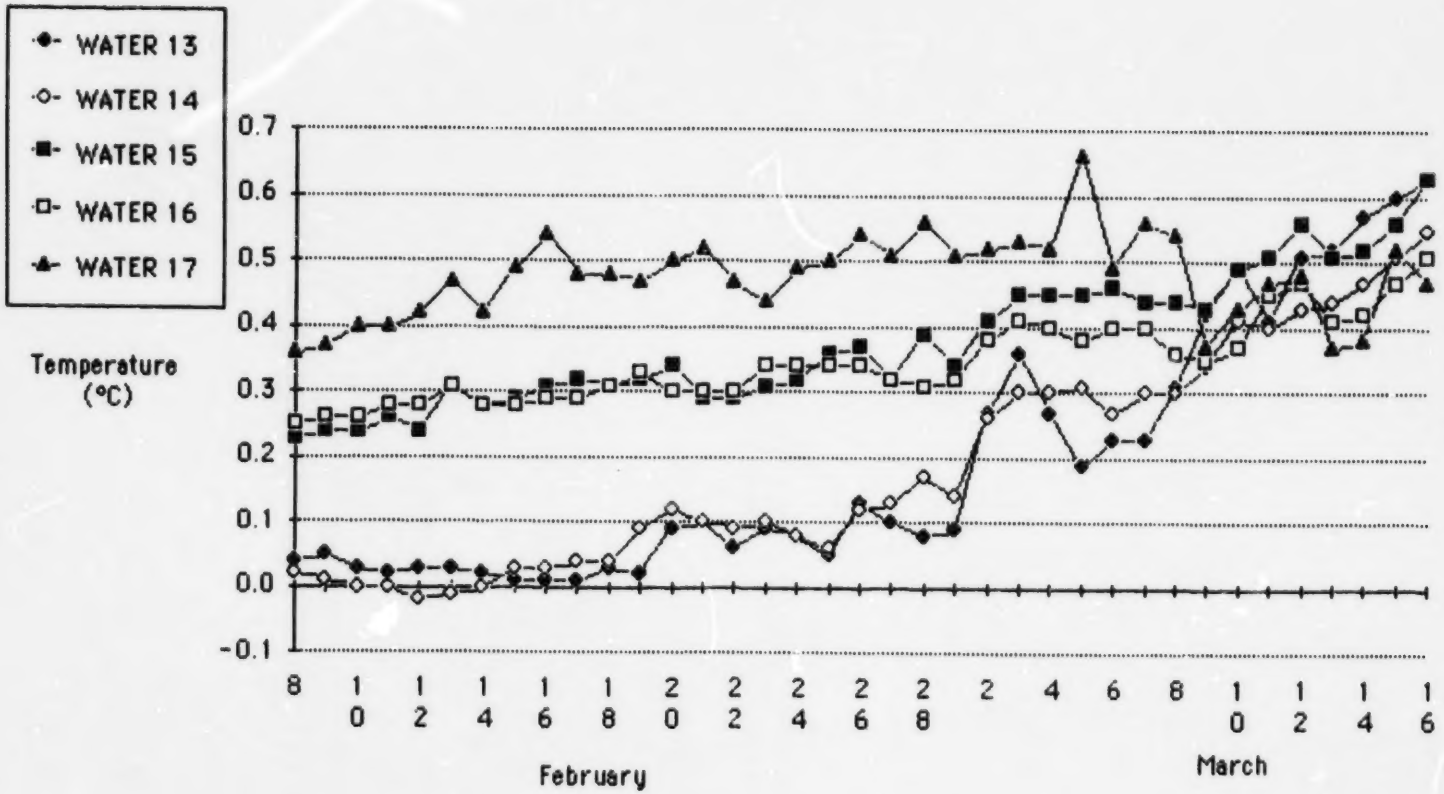


FIGURE 6.5
VERTICAL WATER TEMPERATURES

6.2.2 Ice Temperatures

The ice temperatures during this period were observed to remain very close to 0°C during the daytime and fell to below freezing at night. Water had apparently entered the thermistor cable holes and responded to diurnal air temperature variations. These sensor readings do not, therefore, represent internal ice temperatures.

6.2.3 Air Temperatures

Air temperatures over this period showed a maximum of 5.9°C and a minimum of -11.7°C with a mean temperature of -2.4°C.

6.3 Air Flow Measurements

Beginning with the first operation of the air bubbler system, pressures indicated at each bubbler unit were monitored and noted by hand. The gate valves were used to establish equal pressures at each bubbler unit initially, however problems with the nozzles on some units eventually caused varying pressure readings among the group.

The pressure values measured at each bubbler unit are shown in Table 6.1, for various days during the bubbler operation.

Two problems occurred which affected the bubbler operations and influenced the air flow/pressure measurements. During the early morning hours water often condensed out of the compressed air at the metal hose couplings, and eventually blocked several. This resulted in cessation of bubbler operation most mornings until the ice was cleared. This remained a problem even when dried compressed air was used. The other problem was partially a result of the first difficulty; it arose as a result of the air stoppage. Water would fill the bubbler units and apparently stir up debris which, when the bubbler was turned back on, was sometimes able to block the small nozzle hole, partially or completely.

Some bubbler units operated at visibly higher or lower air flow volumes than others, likely due to blockages or enlarged nozzle holes. After air stoppages in the mornings, often units which had been working well became blocked. Eventually a diver was brought in to clear the units with the most severe problems.

TABLE 6.1

Bubbler Unit Air Pressures (kPa)

Bubbler Number	March 12	March 13	March 14	March 15
1	540	420	580	520
2	540	440	580	540
3	540	420	550	500
4	580	440	600	540
5	570	430	580	580
6	560	420	520	520
7	545	410	520	540
8	520	400	580	200
9	545	420	520	500
10	545	430	520	560
11	540	430	580	500
12	540	430	530	540
13	540	430	520	480
14	540	430	560	500

Rarely did any bubbler unit operate at measured pressures which deviated greater than 5% from the mean measured pressure. This was considered within the accuracy of the pressure gauges.

6.4 Aerial Measurement of Ice Melted

Beginning March 14, aerial photographs from approximately 430 m (1400 ft) above ground level were taken daily through to March 25. (March 19 photos not possible due to weather). These provided a means to measure the area of ice melted due to the bubbler system and it allowed remote observation of a wide area surrounding the test site.

These photographs are reproduced in Appendix B.

Due to icebreaker activity starting in the area March 22, measurements of ice melt can be made with confidence only to March 21. Figure 6.6 shows the daily change in area of ice melted from March 13 through to March 21. The total measured area of ice melted by 0935 March 21 is 689.6 m^2.

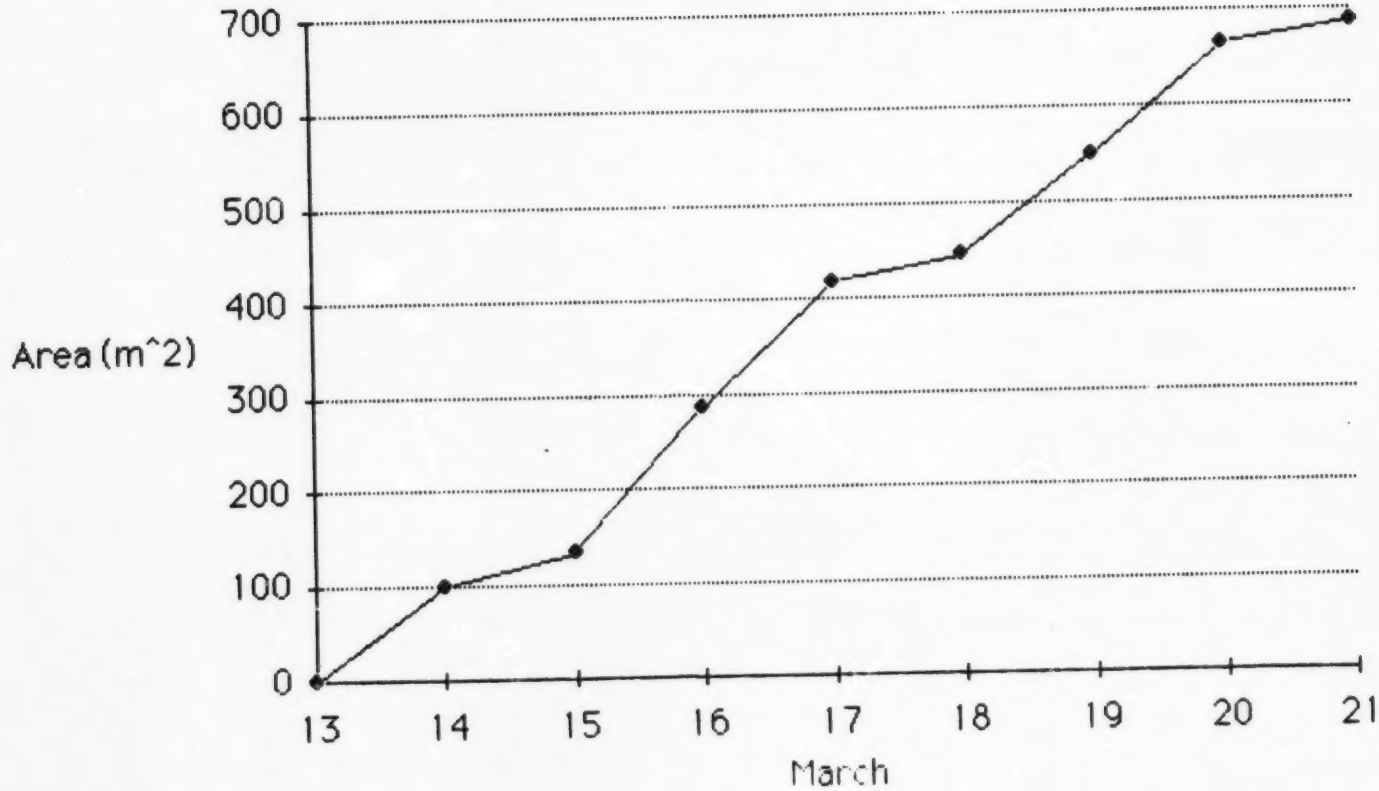


FIGURE 6.6
AREA OF ICE MELTED

6.5 Ice Thickness Measurements

Ice thickness measurements were taken early during the study, as temperature sensors were deployed, and just prior to operation of the bubbler system.

The February measurements were taken at or adjacent to the holes drilled for the placement of the thermistors. The March measurements were taken adjacent to the thermistors and during the first full day of bubbler operation, which resulted in thickness values which were already reduced at certain locations due to bubbler action.

The mean ice thickness in February was 49.8 cm. In March, the mean thickness was 56.1 cm. This represents an increase in thickness of 12.7%.

The changes in ice thickness at the thermistor locations are illustrated in Figure 6.7.

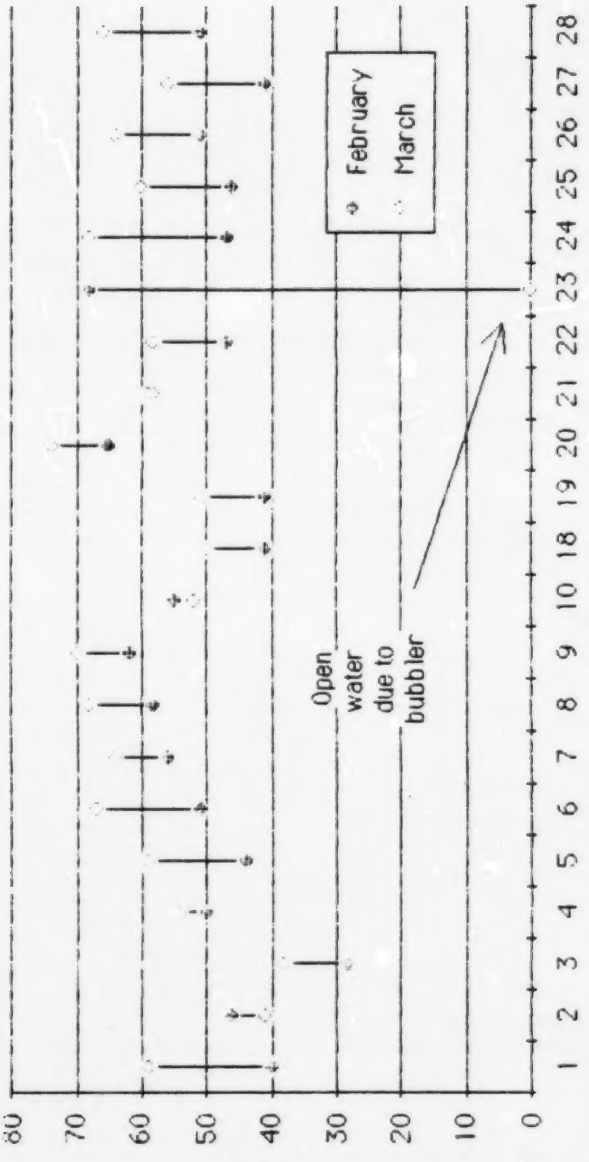


FIGURE 6.7
CHANGES IN ICE THICKNESS DURING STUDY PERIOD

7.0 AIR BUBBLER SYSTEM COSTS

7.1 System Cost Components

In this treatment of the costs of the air bubbler system, costs are divided into categories of capital costs, labour costs, rental or lease costs and operational power/energy costs.

Capital costs include items such as the bubbler units themselves (steel pipe, nozzles, etc), plastic supply air pipe and fittings, support structures. They do not include compressor equipment costs.

Labour costs include annual bubbler system setup and dismantling, and operational labour costs (maintenance, supervision, measurement).

Rental or Lease costs include annual rental of consumables such as miscellaneous hoses and fittings.

Operational power/energy costs include the costs of electricity or other energy source to power the air compressors.

As discussed below, and in Appendix C, certain materials are depreciated at differing rates due to their length of useful lives.

7.2 Cost of Operation of the Air Bubbler

The cost calculations for the installation and operation of the Saskatchewan Wheat Pool 7A bubbler are shown in Appendix C. These calculations use the data from this project and are based on varying depreciation periods. For steel air pipes this period is 10 years; for the plastic distribution piping, which is more susceptible to damage, the period is 3 years.

The estimated cost of removing one square metre of ice cover using the system studied is $ 8.83. The cost of removing one cubic metre of ice cover is $16.04. These costs are based on a total cost per annum of $ 6 095 and a cleared area of 690 m^2 (about 92 m by 7.5 m and 0.55 m thick).

If an operator were considering a new bubbler installation, completed along the full length of the dock face, economy of scale would affect the overall costs. In Appendix C, the calculations are presented also for a 565 m long installation. As before the capital costs of the steel pipes are amortized over 10 years while the plastic pipe has only a 3 year life.

The estimates for a new full length installation suggest that the cost per unit area of removed ice cover would be $ 4.77 per square metre ($ 8.68 per cubic metre), based on a cost per annum of $ 20 755, and a cleared area of about 580 m by 7.5 m by 0.55 m thick.

7.3 Cost Comparisons With Other Systems

The cost per unit area melted by the system under present study with systems which have been tested and studied at Thunder Bay previously indicates that a full scale production air bubbler system of this type is cost-competitive with the other systems.

Table 7.1 indicates the annual cost per square metre melted ice for the air cannon, rake and line air bubbler systems (Abdelnour et al, 1984) compared to the "permanent" system studied during this project.

TABLE 7.1

COST COMPARISONS

SYSTEM:	AIR CANNON*	RAKE	LINE	PERMANENT
ANNUAL COST	$5.82/m^2$	$5.98/m^2$	$19.84/m^2$	$4.77/m^2$

* 5-unit Air Cannon configuration

8.0 THE ICE MELTING EFFECT

The melting effect which caused the clearing of the ice at the study site is attributed to the thermal reserve available at the site. The overall thermal reserve consists of both the heat available from the water and the soil below.

8.1 Thermal Reserve From The water

The thermal reserve available for de-icing is the difference between the average water temperature in the slip and the minimum water temperature at which a bubbler is considered to non-effective. The minimum temperature is about 0.2 to 0.3°C for a conventional bubbler and as low as 0.1°C for high water flow units.

The water thermal reserve was calculated from average daily temperatures obtained from the array of thermistors measuring the temperature at various depths (thermistors 13, 14, 15, 16 and 17). To verify that the temperature at the location of the array was representative of the temperature distribution throughout the test area, temperatures measured at a constant depth (0.46 m from the surface) were compared to thermistor 15 values. The values showed very good agreement throughout the test program.

The thermal reserve, available from the water mass, is defined as the amount of energy/m^2 stored in the water, which can be expressed as:

$$Q_r/m^2 = D \rho C_p T_w$$

where D = depth of water

ρ = density of water (1000 kg/m^3)

C_p =specific heat of water (1 kcal/kg°C)

T_w = average water temperature

Figure 8.1 presents the calulated water thermal reserve for specific dates. This curve indicates that there is a continual increase in the thermal reserve for the period tested. This is attributed to the heat gained continously from the bottom of the slip, as discussed further, below.

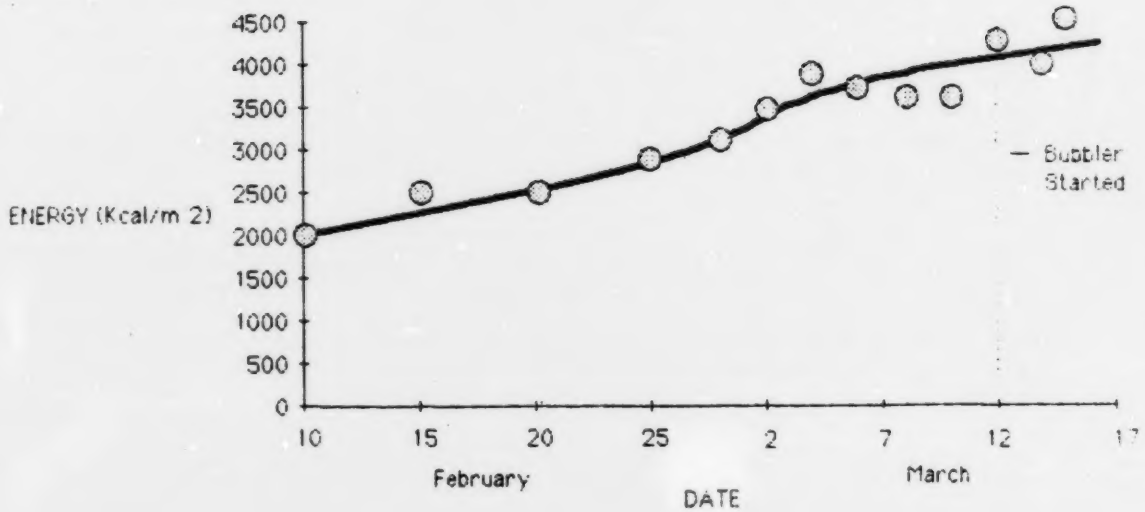


Figure 8 1

WATER THERMAL RESERVE

8.2 Thermal Reserve From The Soil Below

The thermal reserve available in the ground is relatively large, however, only part of the heat is gained by relying on natural convection.

During the summer months, when the air temperature is about 20°C and mixing is high due to the waves and ship movement, the water becomes warm (between 10 to 15°C), and energy is absorbed through the ground beneath the water to depths greater than 5 m. During the freeze-up season, the water becomes cold, cooling also the bottom surface. The degree of cooling of the substrata is influenced greatly by the disturbance of the water due to waves and to ship navigation in and out of the harbour. This period is usually relatively short as freeze-up occurs, and only the top layer of the substrata is cooled down - sometimes to 0.2°C or lower. However, the temperature a few metres below the bottom surface would be still warm; probably this is the warmest period of the year at this depth. When the ice cover is formed and water temperatures are much lower than the ground temperatures, heat is slowly released from the soil on the bottom. This phenomenon has been observed under natural ground surface in clay soil as shown in Figure 8.2, Hutcheon et al (1983).

The average water temperature for the year in the slip is estimated to be 5°C; therefore, at few metres below the bottom surface, the temperature will stabilize at about 5°C as shown in Figure 8.3. This temperature, of course, is an approximate value since the bottom temperature may be influenced as well by the average air temperature because the slip is surrounded by land from three sides.

The results obtained for the test period showed an increase in energy in the water due to ground warming of approximately 2.7 W/m^2 . The heat gained from the soil, calculated from standard heat transfer theories Kreith and Black (1980), is given by:

$$q_k - AK/L\ (T_h - T_c) = AK\Delta T/L$$

where:

q_k = Rate of heat flow by conduction (W/m°C)

A = Unit area (m^2)

K = Thermal conductivity W/m °C

T_h = Higher temperature °C

T_c = Colder temperature °C

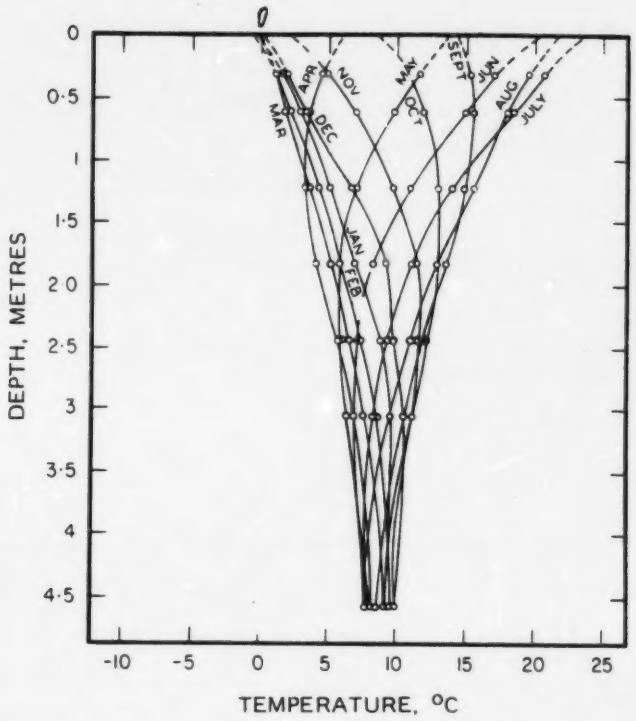


FIGURE 8.2

MONTHLY AVERAGE GROUND TEMPERATURES MEASURED IN CLAY SOIL UNDER NATURAL SURFACE COVER IN OTTAWA (From Abdelnour, 1983)

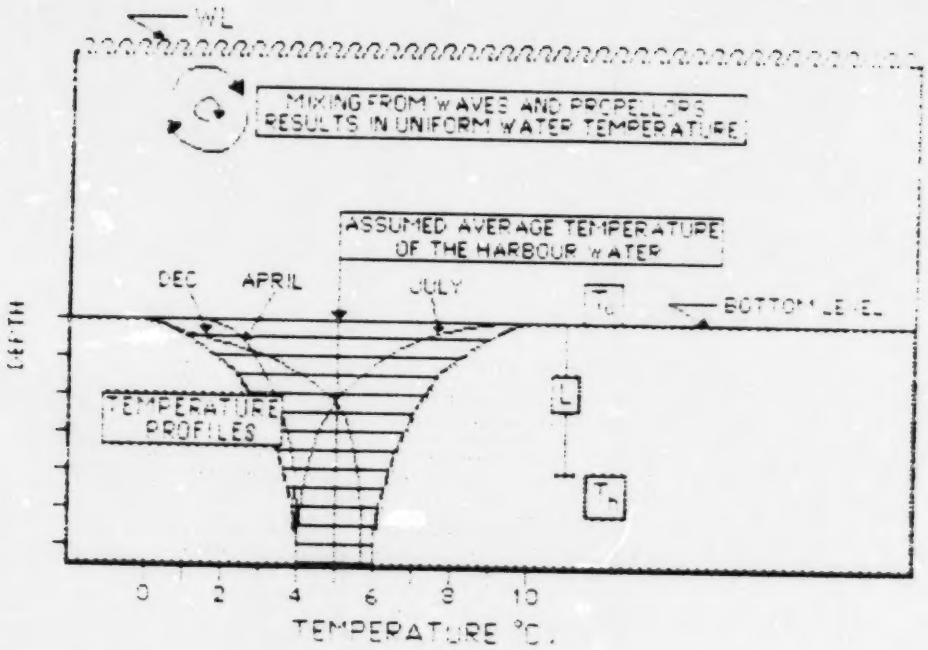


FIGURE 8 3

Soil Thermal Reserve

Providing an undisturbed water mass and in presence of an ice cover, the boundary layer at the soil/water interface exhibits in late winter temperatures in excess of 1 to 2°C as measured earlier by Abdelnour (1983). The calculated heat transferred due to natural convection from the soil to the water is 2.3 W/m°C for a temperature difference of ΔT of 1°C between the soil/water interface and at one metre depth below (K = 2.27 W/m°C for high water content soils).

8.3 The Melting Effect

The melting effect, then, is explained by vertical transfer of warmer water from depth to the surface, and to the ice. The warmer water at the bottom has as a heat source the stored heat energy released from the soil below, the walls of the slip and additional, warmed water surrounding the affected area.

The motion of the water body, and resulting transfer/conection of water, is the key to the success of the operation.

Ship Movement

A sudden increase in the average water temperature was observed at approximately the end of February. This date coincided with the start of the icebreaking operation in the harbour. The icebreaker operation may have induced some water movement and resulted in higher heat gain from the bottom. The calculated heat gain from the bottom supports this assumption. The heat gain can be increased threefold if the temperature, at the boundary layer, can be maintained at 0.5°C rather than 1 or 2°C by introducing some flow at that level. The heat generated from a temperature difference ΔT of 2.5°C will result from a heat flow rate in excess of 5.7 W/m°C.

Bubbler in Operation

The average water temperature distribution, following the bubbler operation on March 12, is shown in Figure 8.4. The bubbler appears to mix the water uniformly and melt the ice at a rate of about 100 m^2 per day. There was no significant change of the water temperature, despite on one hand, the heat lost from melting the ice and exposing the water surface to the cold air above, and on the other hand, the heat gained from the ground and the solar radiations from the water surface.

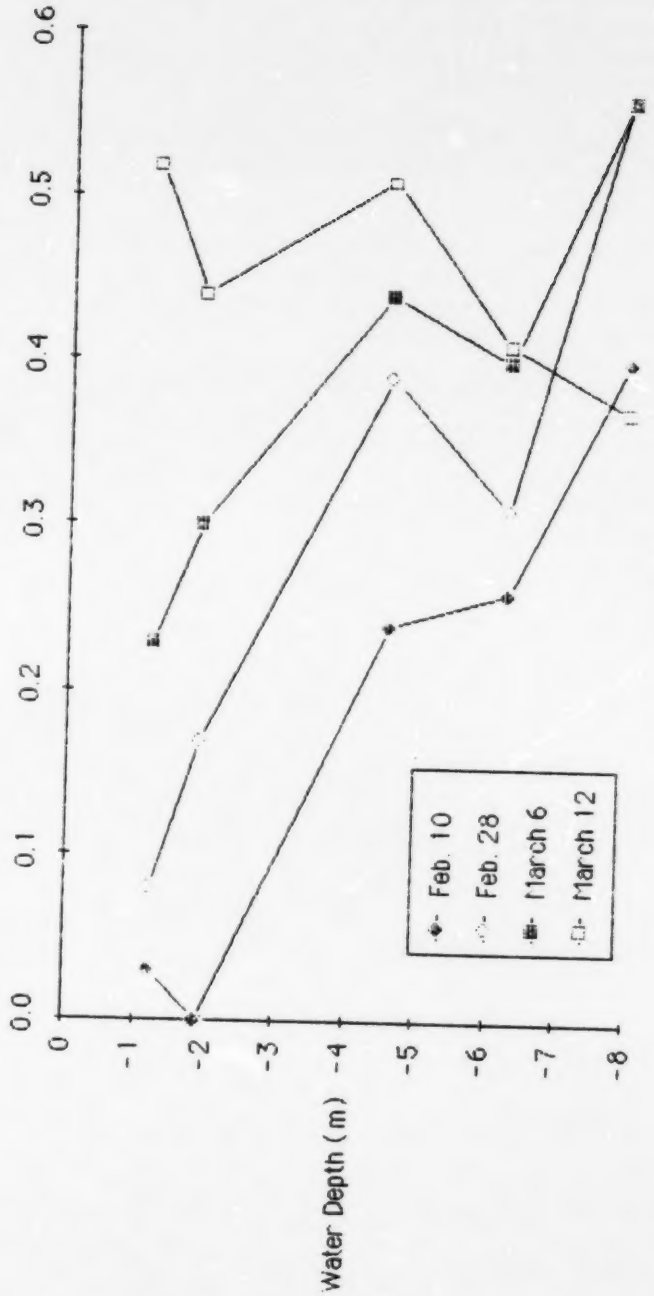


FIGURE 8.4
WATER TEMPERATURE PROFILES

The area where the ice was cleared over an 8 day period was 700 m^2. This area is about 4% of the total slip area. The ice thickness was about 0.75 m. The heat required to melt 700 m^2 of ice is 67.5 x 10^6 calories/m^2. The amount of heat available in the column of water below the ice is only 4 x 10^6 calories/m^2 or about 6% of the necessary energy to clear the amount of ice measured in this study. Therefore, to melt the volume of ice cleared during the period with the bubbler in operation, energy from the surrounding water in the slip and other sources of heat discussed in Abdelnour et al (1984) must have been available.

This fact has been observed during previous tests where increases, rather than decreases, in water temperature during bubbling have been noted (Ashton, 1982). The thermal reserve available in the water was found to be increasing while bubbling was in operation.

As a result of measuring the temperature about a month before the bubbler was operational, it has been shown that the thermal reserve of the water increased by 100% in one month, mostly from the soil below the water. It was also possible to detect the influence of water movement on heat transfer from the bottom, effectively increasing the overall thermal reserve.

9.0 CONCLUSIONS

This study was designed to answer four prime questions concerning the specific use of a recently installed wall-type bubbler system and the general performance of a bubbler system in the slip at Saskatchewan Wheat Pool 7A (refer to Section 1.2).

The bubbler system has been evaluated to be highly effective in moving deep water vertically up to the ice/water interface. This was interpreted from the temperature changes which took place in the region of the bubbler system, where the general water body increased in temperature rapidly, apparently from mixing with the warm bottom water and from warming of moving lower water from the soils beneath the slip.

The rate of ice melt caused by the bubbler system was approximately 100 m^2/day. As shown in Section 8.2, Figure 9.1, this is approximately the same rate as the Rake Diffuser air bubbler system tested previously at Thunder Bay.

It was determined from this study that the source of the melting effect is a complex combination of latently warm water in the bottom of the slip and stored heat energy in the soils beneath the slip, with a speeded transfer mechanism driven by the bubbler-induced moving water. Thus, the melting effect is a result of stored heat energy from previous summer, brought speedily to the surface by moving water, propelled by the air bubbler system.

The cost of the air bubbler system, based on the existing and a similar full-slip system, are \$8.33/m^2 and \$4.77/m^2 , respectively.

This study was a successful application of known field techniques to an extension of the air bubbler technologies, and it has resulted in a greater understanding of the processes which are involved, as well as demonstrating the capabilities of this particular air bubbler system. This study has also raised more questions, and leads naturally to further examination of better and more reliable methods of ice management with air bubbler systems (see Section 10).

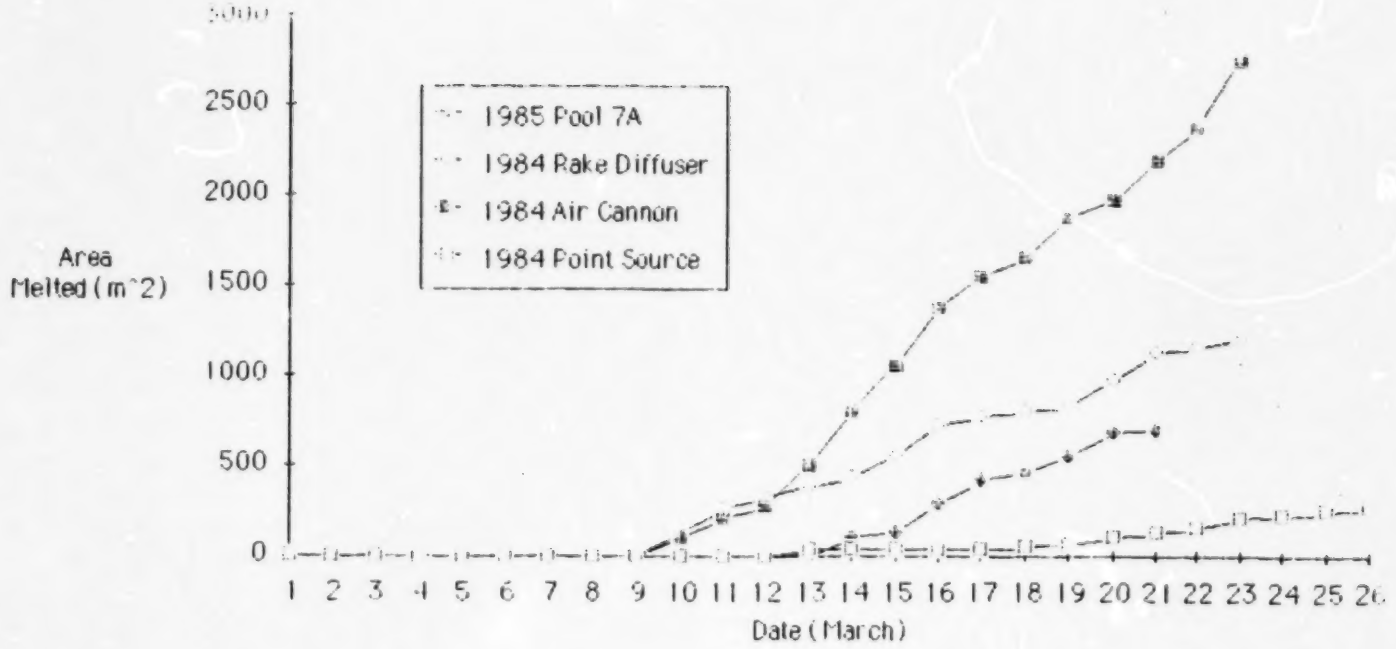


FIGURE 9.1
AREA MELTED BY VARIOUS BUBBLER SYSTEMS
AT THUNDER BAY

10. RECOMMENDATIONS

The results of this study and, in particular, the operational experience gained during this study, have led to a number of recommendations for future work, study and operational procedures.

Operational Procedures

It is recommended that prior to operation of the present bubbler units again, the nozzles be examined for consistent diameter. It was not possible to obtain similar air flows among all the bubbler units and it is felt that one or two of these had unusually large nozzle holes.

Prior to Spring operation, the nozzles should be removed and thoroughly cleaned, and the down pipes cleaned by blowing air through the bubbler units without nozzles. This should remove the debris which was a problem during this study.

Consideration should be given to the use of slightly larger nozzles for the practical reasons of avoiding the above procedures; alternatively, nozzles could be developed which could be opened wider or removed from the surface for debris clearing purposes.

There were problems with freezing condensation in the hose couplings. It is recommended that a condensing manifold always be used with such a system, and drained daily.

The air supply was more than adequate for the prototype system; likely a reduction in operating pressure to 60-100 kPa would be satisfactory.

Research

Additional research which would assist in understanding the processes occuring during bubbling include: seasonal vertical temperature measurement in several places, in one slip to be used for future research, including water and soil to 2 m depth; use of sensitive low velocity bottom-located current meters in nearby regions of the bubbler units during bubbling operations; use of inert neutrally buoyant tracer spheres, for tracking water flows during bubbling; monitoring in greater detail the vertical temperature profile in the ice right at a bubbler unit.

This bubbler unit worked well, so no major design improvements are recommended, except as mentioned above with respect to maintenance: variable diameter nozzle designs, operable from the surface, might assist in clearing debris from bubbler units.

11.0 BIBLIOGRAPHY

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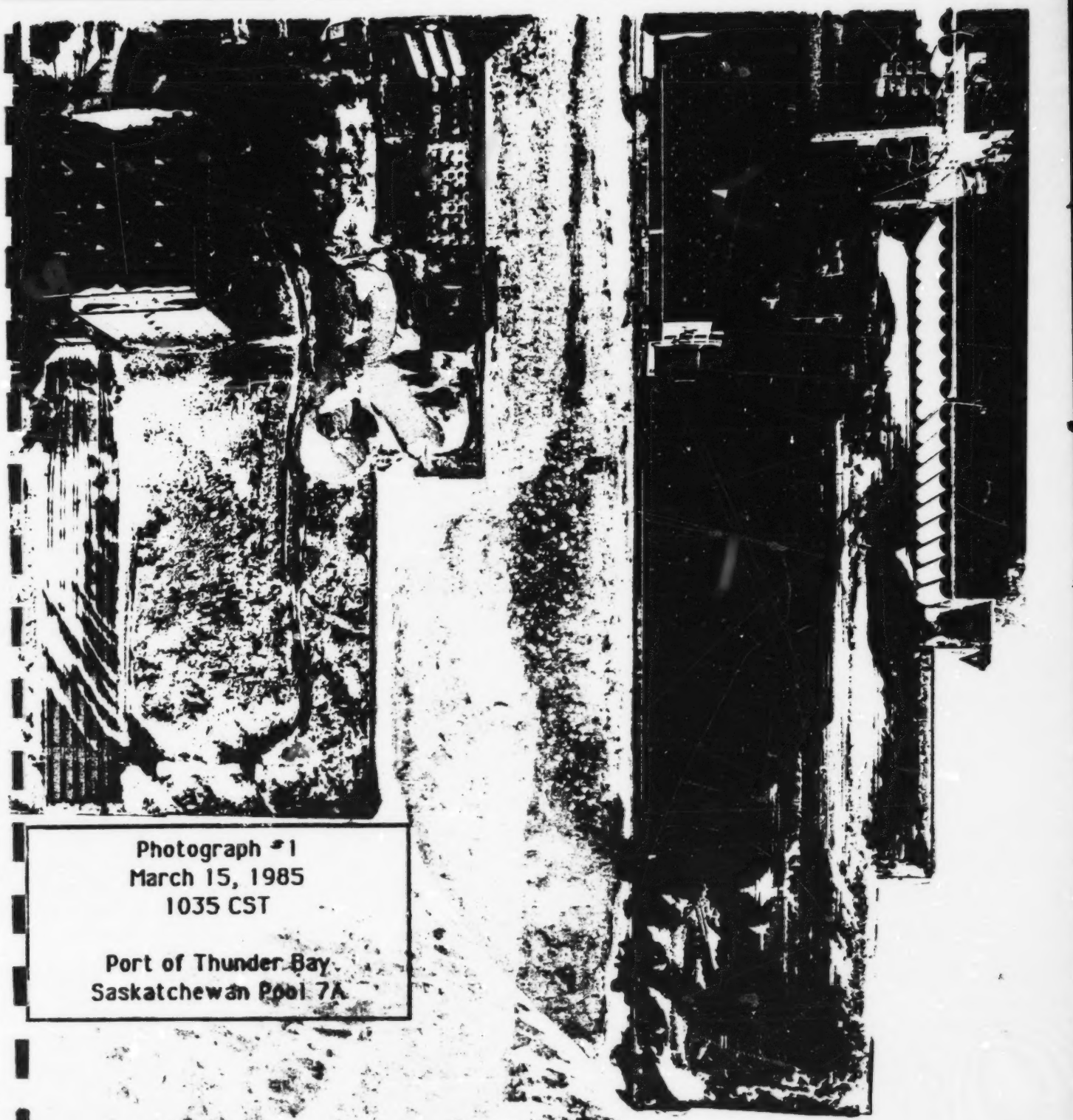
APPENDIX A

TEMPERATURE DATA

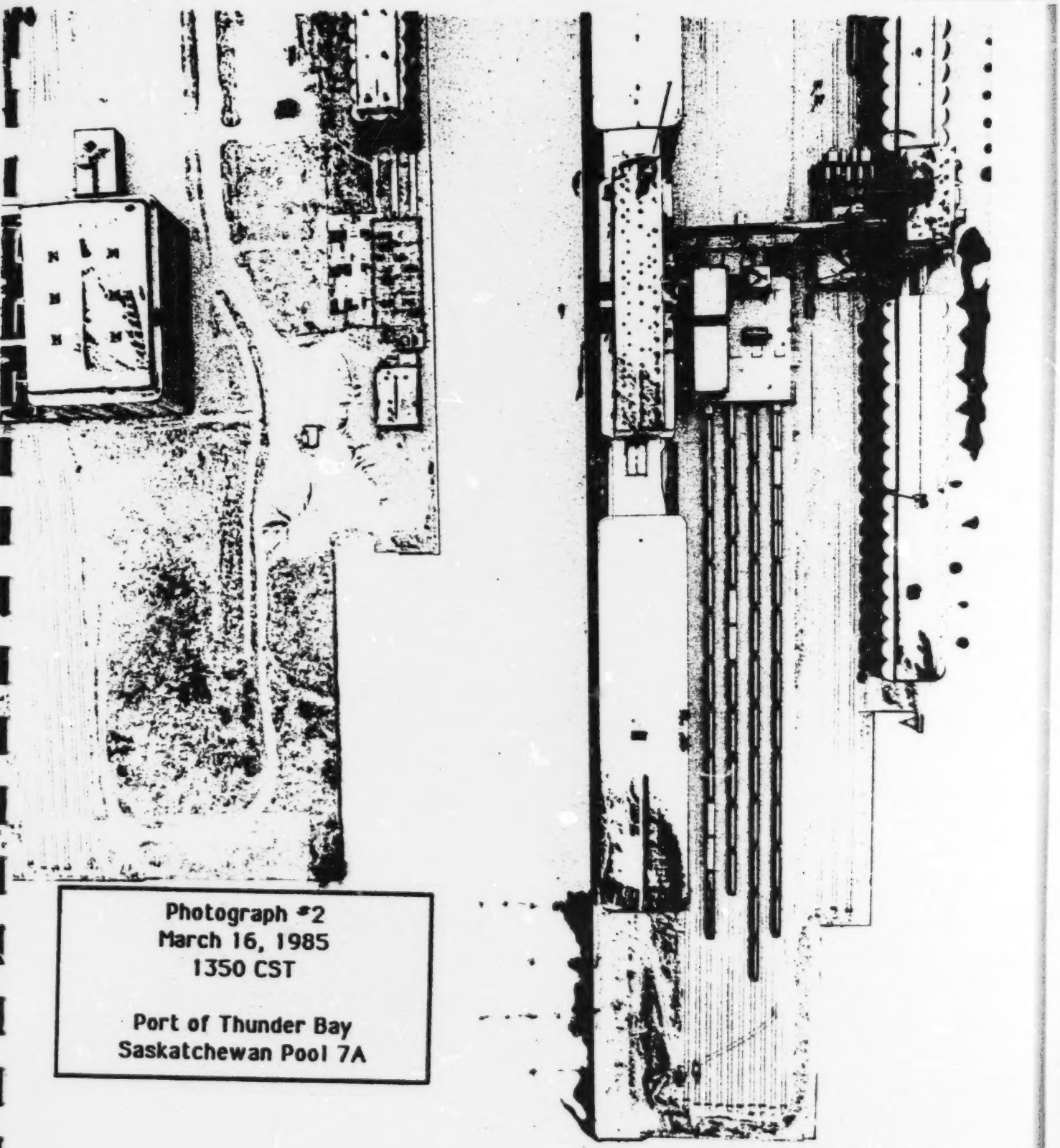
APPENDIX B

COLOUR AERIAL PHOTOS



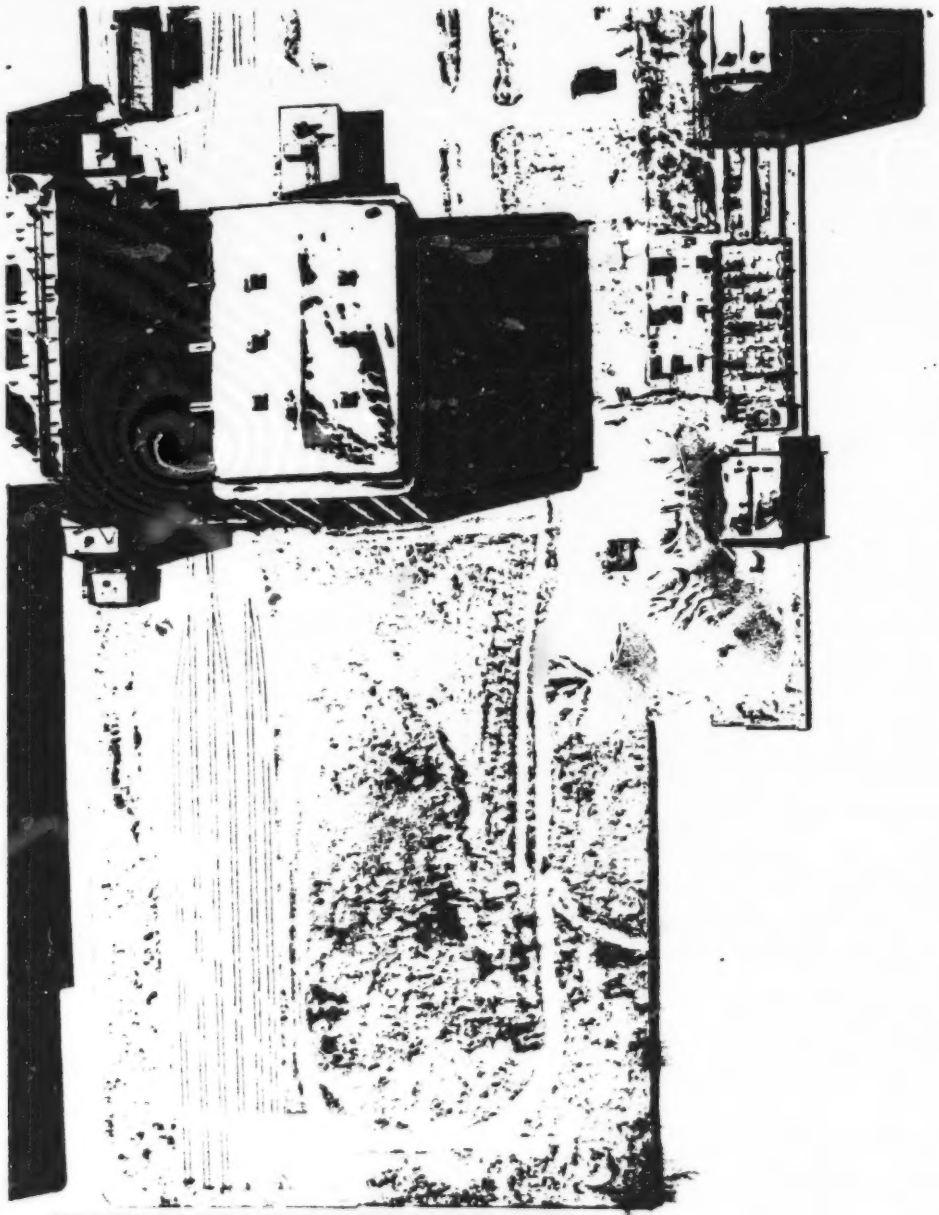
Photograph #1
March 15, 1985
1035 CST

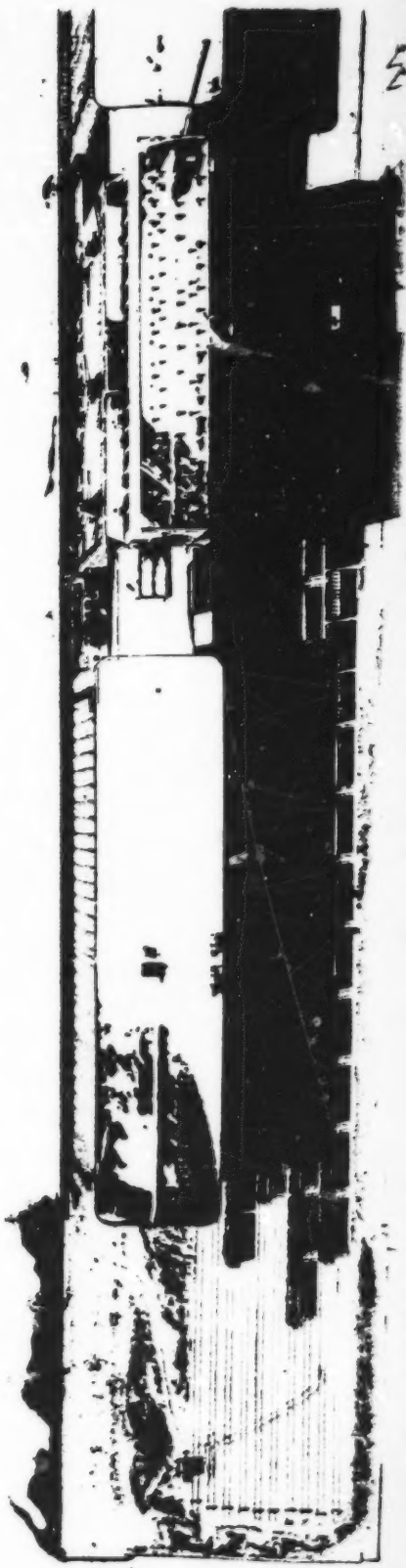
Port of Thunder Bay
Saskatchewan Pool 7A



Photograph #2
March 16, 1985
1350 CST

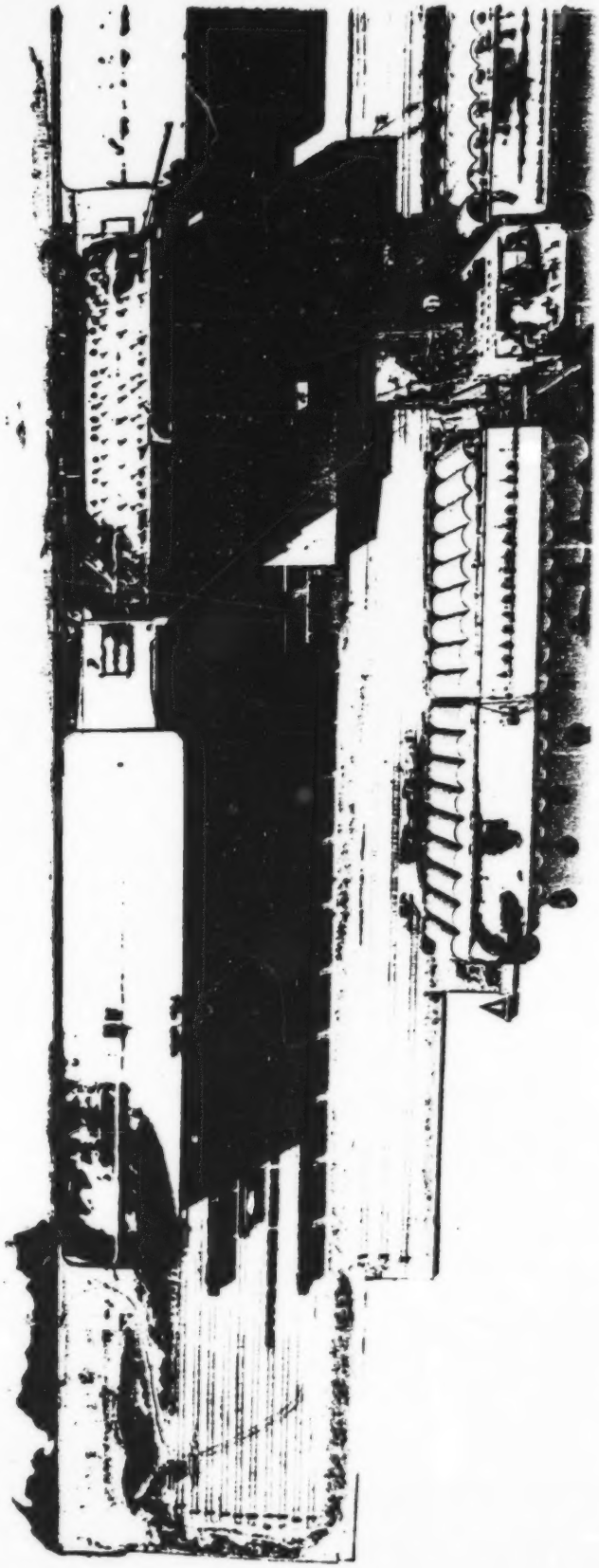
Port of Thunder Bay
Saskatchewan Pool 7A





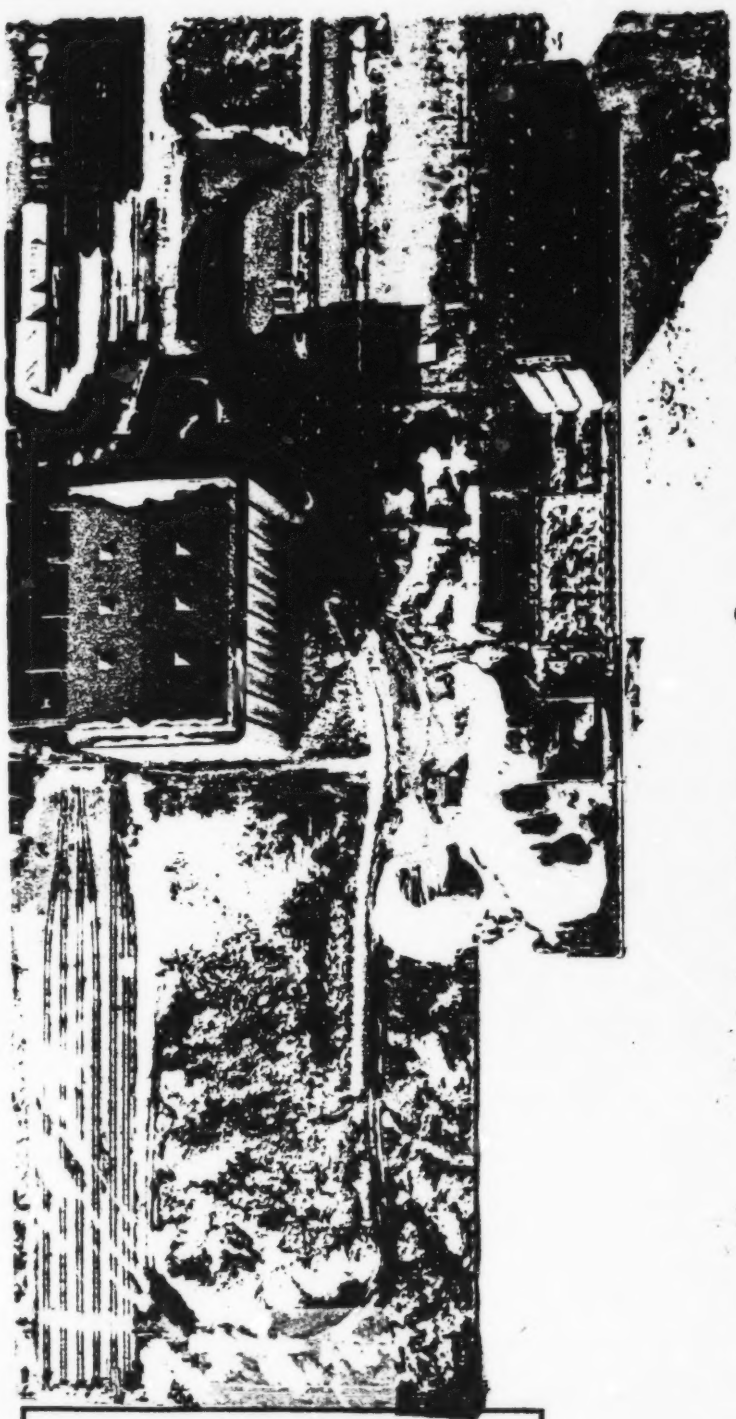
Photograph #3
March 17, 1985
1230 CST

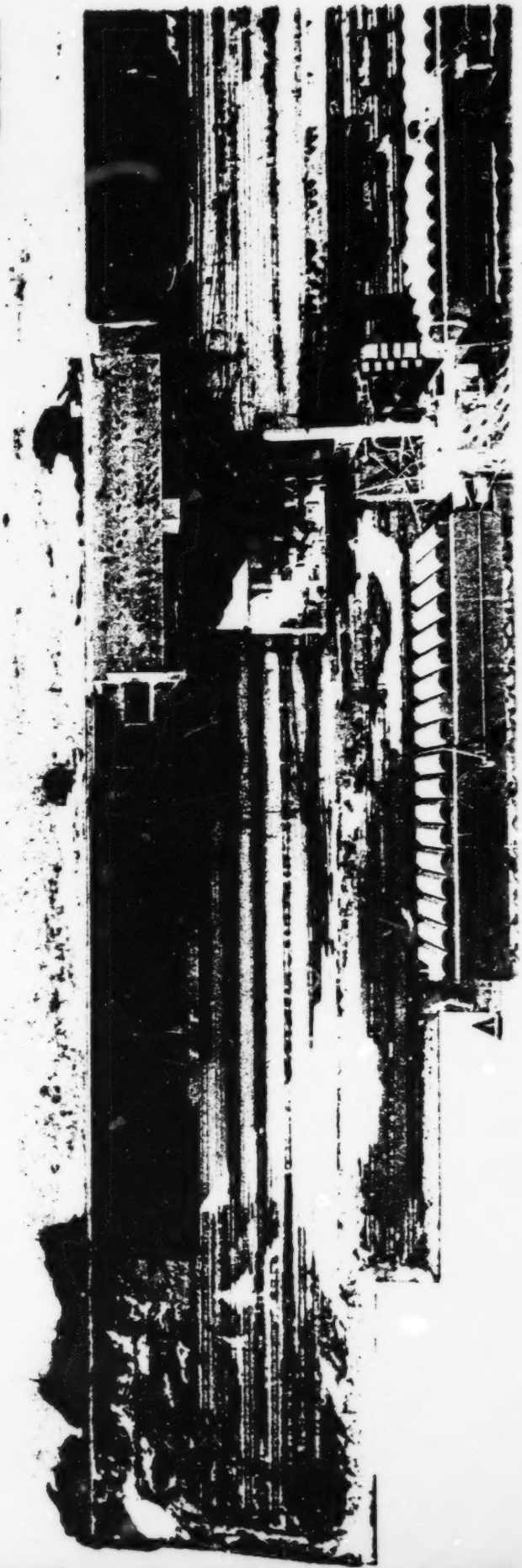
Port of Thunder Bay
Saskatchewan Pool 7A



Photograph #4
March 18, 1985
1115 CST

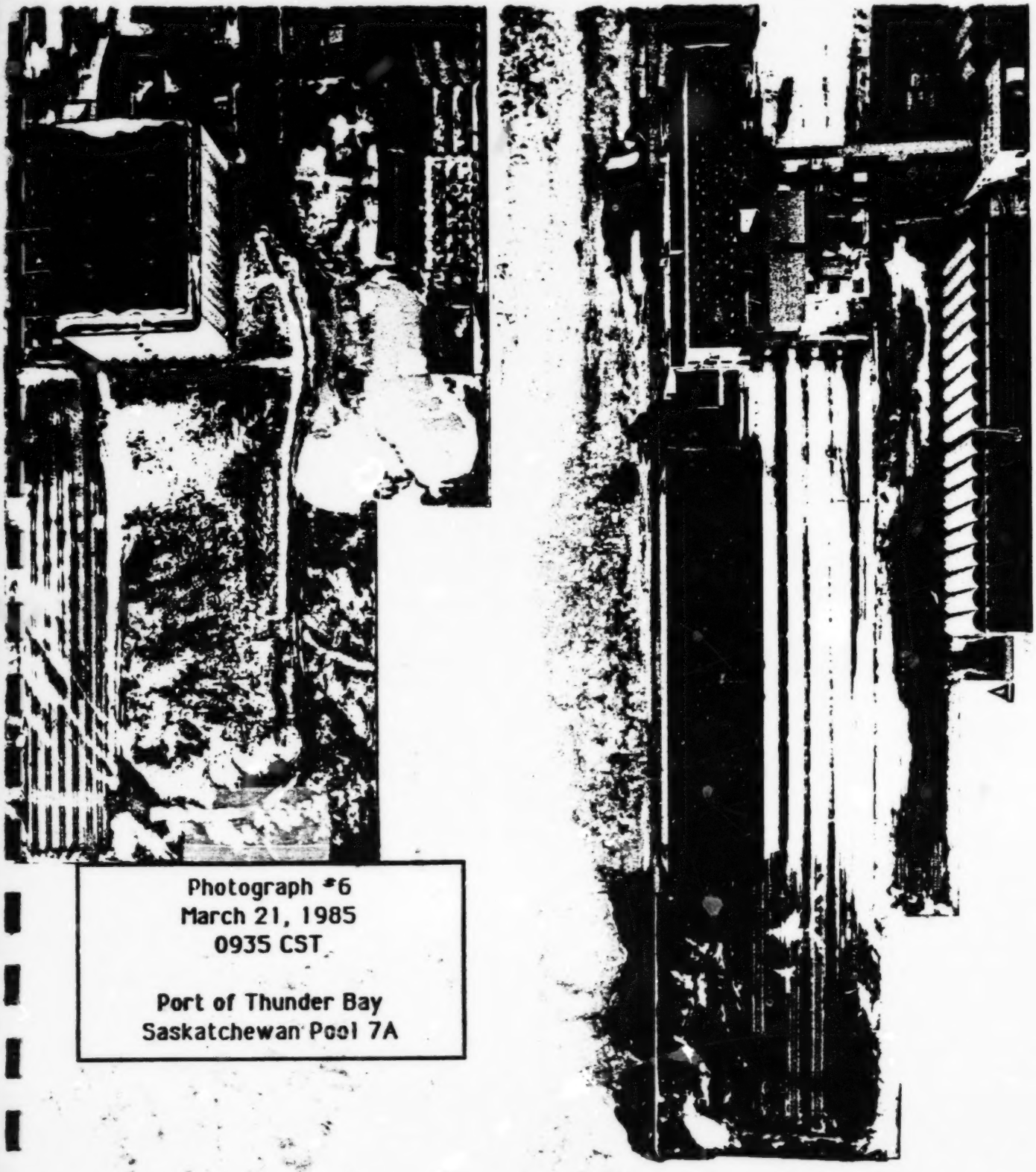
Port of Thunder Bay
Saskatchewan Pool 7A





Photograph #5
March 20, 1985
0950 CST

Port of Thunder Bay
Saskatchewan Pool 7A

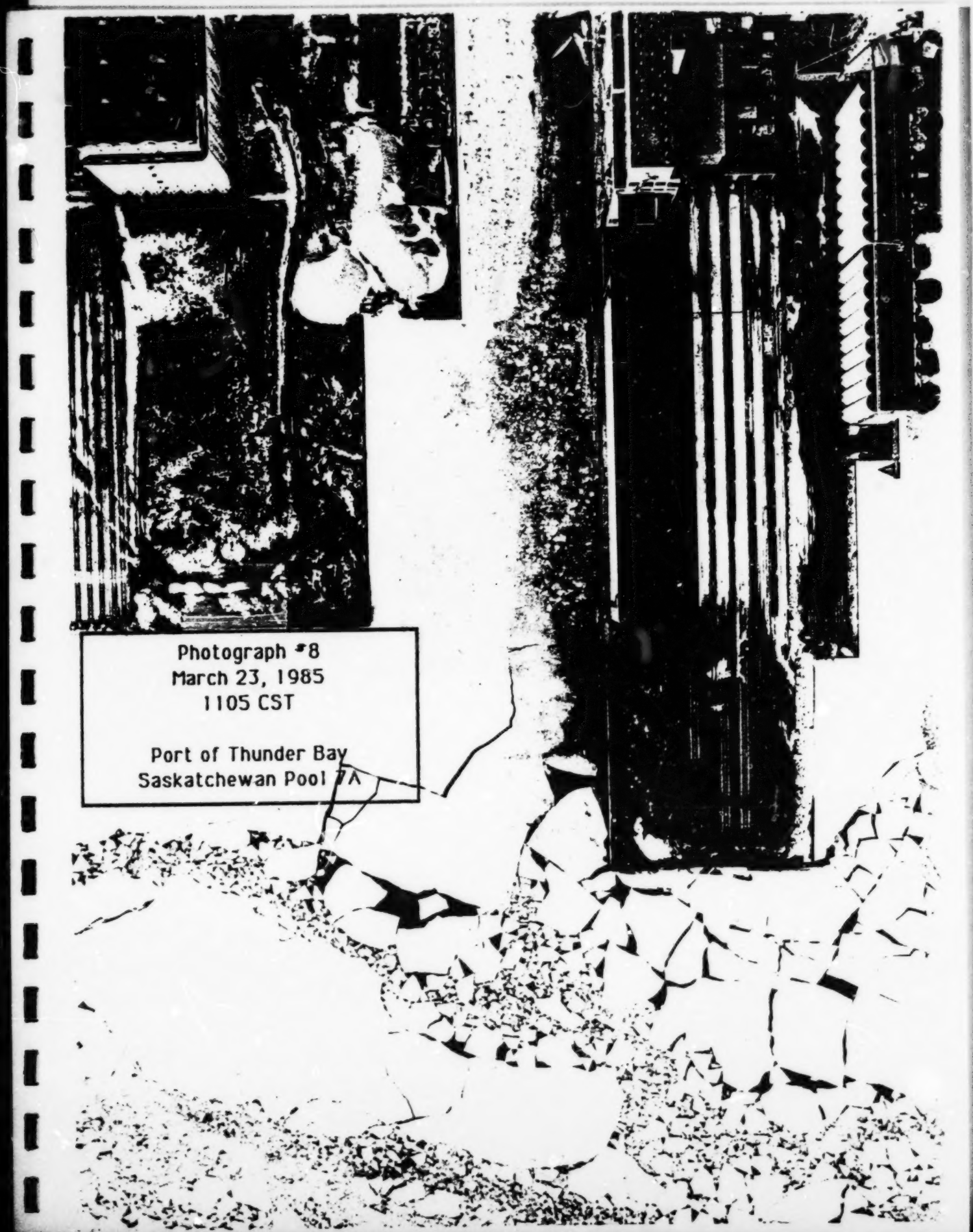


Photograph #6
March 21, 1985
0935 CST

Port of Thunder Bay
Saskatchewan Pool 7A

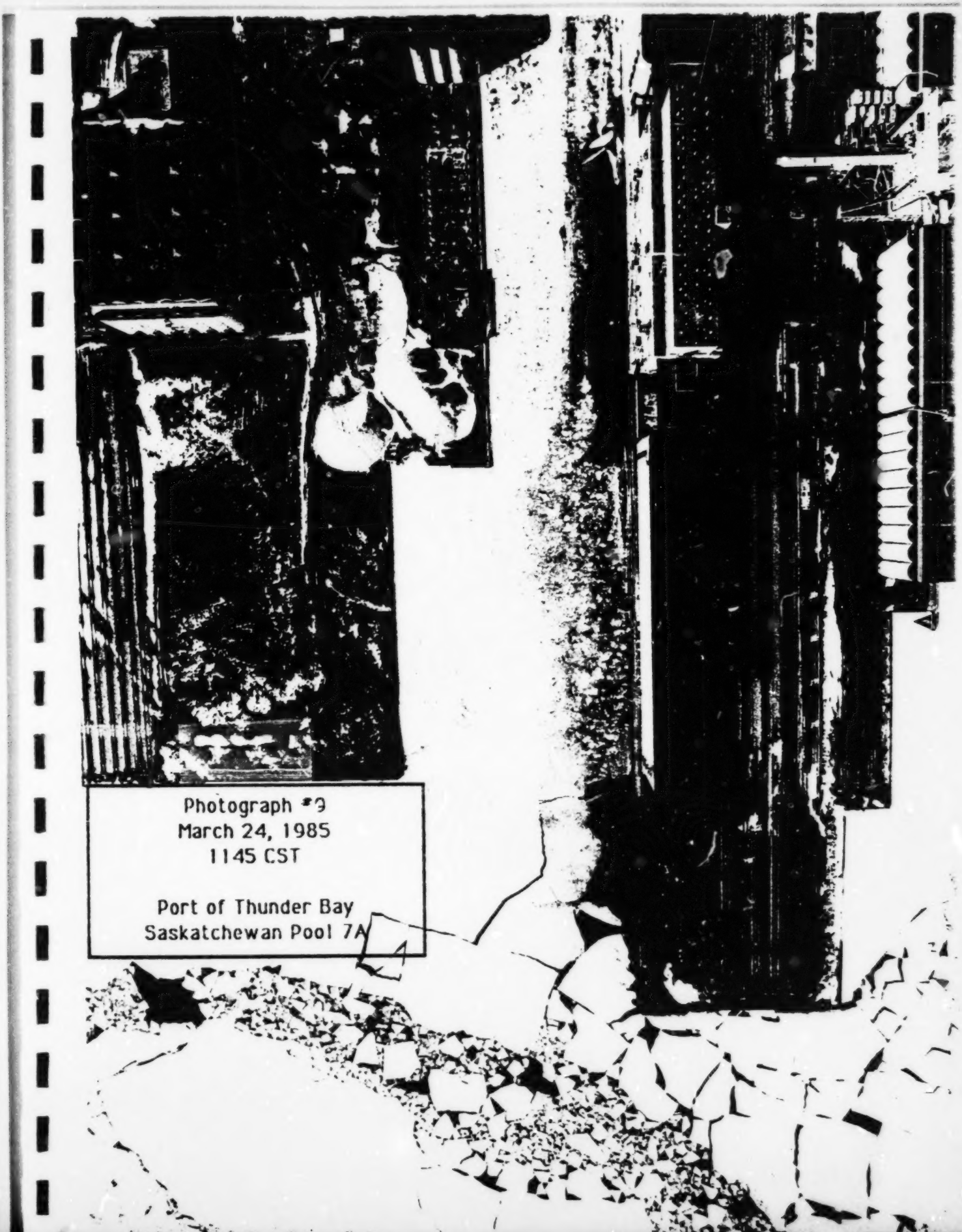
Photograph #7
March 22, 1985
1405 CST

Port of Thunder Bay
Saskatchewan Pool 7A



Photograph #8
March 23, 1985
1105 CST

Port of Thunder Bay
Saskatchewan Pool 7A



Photograph #9
March 24, 1985
1145 CST

Port of Thunder Bay
Saskatchewan Pool 7A

Photograph #10
March 25, 1985
1120 CST

Port of Thunder Bay
Saskatchewan Pool 7A

APPENDIX C

COST CALCULATIONS

APPENDIX C

COST CALCULATIONS

Area of ice cover removed	690 sq. m
Average thickness of ice in the area	550 mm.
Volume of ice removed	380 cu. m

1. Steel Pipes at the Wharf Structuree

Capital costs	$4,200.00 (ref. 1)	
Depreciation period	10 years	
Interest rate	10 percent	
Annual portion of capital cost		$ 420.00
Interest on capital p.a.		$ 420.00

2. New plastic pipe air supply along wharf

Distance	260 m	
Depreciation period	3 years (potential for damage)	
Cost of Pipe (50 x 50 each side)	$ 1.00 per m	
Cost of clamps (1 per m)	$ 7.50	
Total cost of materials	$ 1,950.00 (260m x $7.50)	
Annual portion of capital cost		$ 650.00
Interest on capital p.a.		$ 195.00

3. Installation of Air Bubbler in Spring

Labour costs (ref. 1)	
2 man days at $20.00 per hour	$ 320.00
Diver costs (ref. 2)	
4 hours (min.) at $130/hr	$ 520.00

4. Rental charges for hoses etc. (ref. 2)

Rental charges for 50mm hose, $150/month per 15 m
Rental charges for 25mm hose, $100/month per 15 m

Lengths required - (50mm x 45m) + (25mm x 210m)

Rental cost (based on one month)

50 mm- 45/15 x $150.00	$ 450.00
25 mm- 150/15 x $100.00	$1,400.00

5. Power Costs

Unit cost - $0.03 per kW hour (ref. 1) including start-up charge from Thunder Bay Hydro Power
Used - 30 kW x 0.3 (utilization factor)
Time of Bubbling - 15 days

Power cost - 15 d x 24 x 30kW x 0.3 x $0.03	$ 100.00

6. Operational labour costs (ref. 1)

0.5 man days per day 15 x 0.5 x $20.00 hour	$1,200.00

7. Demobilization costs (ref.1)

2 man days x $20.00 hour	$ 320.00
Truck charges	$ 100.00

8. Cost Totals

Per year, based on 15 days bubbling	$6,095.00

9. Unit Costs

Cost per unit (sq.m) of AREA removed	$ 8.83
Cost per unit (cu.m) of VOLUME removed	$16.04

10. References

Ref. 1 Telecon Stone (Sask. Pool 7A)/Miller May 1985
Ref. 2 ACL calculations based on Thunder Bay costs.

ESTIMATED CALCULATIONS OF THE COST TO BE INCURRED IN AN EXTENDED AIR BUBBLER SYSTEM ON A REGULAR BASIS

Length of the dock over which bubbler fitted	565m
Width of open water desired	7.7m
Area of open water required	4,350 sq. m
Multiplier for area - 4,350/690	6.3
Multiplier for length - 565/90	6.3m

1. Steel pipes in the Wharf Structure

Capital costs (6.3 x 14 x $ 300.00)		$26,400.00	
Depreciation period	10 years		
Interest rate	10 per cent		
Annual portion of the capital p.a.			$2,640.00
Interest on capital p.a.			$2,640.00

2. Plastic supply pipe along wharf

Distance	565 m	
Cost per metre	$7.50 (See Appendix)	
Total cost of materials	$4,240.00	
Depreciation period	3 years	
Annual portion of the capital cost		$1,415.00
Interest on the capital p.a.		$ 425.00

3. Installation of the system in spring

Labour costs 6 man days at $20.00 per man hour	$ 960.00
Diver costs 8 hours at $130.00 per hour	$1,040.00

4. Rental charges for hoses, etc

50mm dia x 45m cost	$ 450.00
25mm dia x (80 x 15 m) cost	$8,000.00

5. Power Costs

(30 kW x 1.0) x 15 days x $0.03	$ 324.00

Note: the utilization factor is now 1.0
Ref. 1 in Appendix suggested that additional capacity not required.

6. Operational labour costs

one man (full time) at $20.00 per hour x 15 days	$2,400.00

7. Demobilization costs

6 man days at $20.00 per man hour	$ 960.00
Truck charges	$ 250.00

8. Cost Totals

Per year (based on 15 days operation)	$20,755.00

9. Unit Costs

Cost per unit (sq. m) of AREA removed	$ 4.77
Cost per unit (cu. m) of VOLUME removed	$ 8.74